BONUS! Guide to the Night Sky 2016

The life and times of **Stephen Hawking** p. 50

Dawn mission reveals dwarf planet **Ceres** p. 44

JANUARY 2016

Astronomy®

The world's best-selling astronomy magazine

TOP 10 SPACE STORIES OF THE YEAR

- New Horizons reveals Pluto close-up
- Rosetta zooms in on comet
- Youngest cluster of galaxies imaged
- A watery moon of Saturn exposed
- Closing in on dark matter

AND MORE p. 22

www.Astronomy.com

BONUS ONLINE CONTENT CODE p. 4

Vol. 44 • Issue 1

A stellar gift-giver's guide p. 56

Bob Berman on marketing the cosmos p. 10

Now with **5% PROMO-CODE!**

universe2go
My personal Planetarium.

YOUR JOURNEY THROUGH THE COSMOS!

Universe2go combines a real view of the stars with the digital world. Look to the heavens and discover constellations, planets, and galaxies.

WHAT IS UNIVERSE2GO?

Universe2go is a completely new, augmented-reality star viewer and smartphone app, which shows you the starry night sky in stunning detail! Place your smartphone in the viewer and observe the night sky with numerous, additional bits of information as well as sensational close-ups of various celestial bodies.

- Images of all **88 constellations** of the heavens
- **Close-ups** of planets, galaxies, star clusters and nebulae
- More than three hours of **audio explanations**
- Narratives of **Greek mythology**
- Enjoyable exploration in **quiz mode**

ORDER NOW

INFINITE POSSIBILITIES

Leisure time

Family

Education

Home use

- Free shipping
- Delivery in 2-5 days
- Secure payment options
- Exclusively available here
- 14-day money back guarantee

CUSTOMER REACTION
"Great what is possible today. Learning and fun together for the whole family."

Order now with a **5% READER'S REBATE**!
Promo-code: **u2goatm15** (valid until 12/31/2015)

www.**universe2go**.com

$99 including Universe2go app unlock code

Omegon is a part of nimax GmbH. You will find more information about our company at www.nimax.de. Prices are subject to change and errors are excepted.

Address
omegon • c/o nimax GmbH
Otto-Lilienthal-Straße 9 • 86899 Landsberg
Germany

Phone
+49 8191 94049-61

Mail
service@universe2go.com

Opening hours
Monday to Friday
9:00am - 5:00pm
Central European Time

made in Germany by omegon

Online Content Code: ASY1601
Enter this code at: **www.astronomy.com/code**
to gain access to web-exclusive content

CONTENTS

22

FEATURES

22 COVER STORY
Top 10 space stories of 2015
Astronomers find signs of dark matter close to home, unravel the mystery of a famous supernova, and take a trip to Pluto.
LIZ KRUESI

32
Is a cosmic career for you?
If you're set on an astronomy-related job, spend some time listening to the experts.
STEPHEN G. CULLEN

34
Ask Astro

36
The Sky this Month
MARTIN RATCLIFFE AND ALISTER LING

38
StarDome and Path of the Planets

BONUS INSERT!
***Astronomy*'s 2016 Guide to the Night Sky**
This handy four-page insert will keep you looking up all year.

44
Dawn mission reveals dwarf planet Ceres
With lowlands, highlands, weird white spots, and even a pyramid, the largest object in the asteroid belt is unlike anything else in the solar system. **ERIC BETZ**

50
The life and times of Stephen Hawking
Next summer's Starmus Festival will constitute a once-in-a-lifetime tribute to the great theoretical physicist. **DAVID J. EICHER**

56
Holiday gift-giver's guide
If astronomy is on your gifting list, here's how to please without breaking the bank.
PHIL HARRINGTON

60
Tales of the Astronomers Royal
Personal feuds, world wars, and revolutionary science are all part of the history of this British post.
RAYMOND SHUBINSKI

JANUARY 2016
VOL. 44, NO. 1

CFHT/COELUM - J.-C. CUILLANDRE & G. ANSELMI

ON THE COVER

The Cone Nebula (NGC 2264) glows from the light of hot stars, light that will eventually destroy all but its densest shadows.

COLUMNS

Strange Universe 10
BOB BERMAN

For Your Consideration 14
JEFF HESTER

Secret Sky 18
STEPHEN JAMES O'MEARA

Observing Basics 20
GLENN CHAPLE

Cosmic Imaging 64
ADAM BLOCK

Astro Sketching 68
ERIKA RIX

QUANTUM GRAVITY

Snapshot 9
Astro News 12

IN EVERY ISSUE

From the Editor 6
Letters 10, 20, 64
New Products 66
Web Talk 69
Advertiser Index 71
Reader Gallery 72
Breakthrough 74

Visit **Astronomy.com/toc** for bonus material — it's exclusive to *Astronomy* magazine subscribers.

Astronomy (ISSN 0091-6358, USPS 531-350) is published monthly by Kalmbach Publishing Co., 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Periodicals postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to *Astronomy*, 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Canada Publication Mail Agreement #40010760.

ONLINE FAVORITES >>

Go to **www.Astronomy.com** for info on the biggest news and observing events, stunning photos, informative videos, and more.

Dave's Universe
The inside scoop from the editor

Trips & Tours
Travel the world with the staff of *Astronomy*

The Sky this week
A daily digest of celestial events

Weekly Podcast
Observing targets for all skywatchers


ORION®
EVERYTHING FOR THE AMATEUR ASTRONOMER
CELEBRATING 40 YEARS
FREE SHIPPING on orders of $250 or more
INSTALLMENT BILLING on orders of $350 or more
NO SALES TAX* on most orders
For 40 years and counting, our commitment to quality, service and support has made Orion your one-stop source for affordable amateur astronomy gear.
Orion® 60mm Multi-Use Guide Scope with Helical Focuser #13008 $219.99
Orion® Sirius Pro AZ/EQ-G Computerized GoTo Telescope Mount #10088 $1599.99
NEW PRODUCT 2015
Orion® StarSeeker™ IV 150mm GoTo Reflector Telescope #13161 $579.99
Orion® StarSeeker™ IV 130mm GoTo Reflector Telescope #13160 $499.99
Orion® Ritchey-Chrétien Astrograph Telescopes
6" #8268 $499.99
8" #8267 $999.99
10" #8266 $2799.99
Orion® StarSeeker™ IV 127mm GoTo Reflector Telescope #13163 $699.99
Orion® Orion 40th Anniversary SkyQuest™ XT8 Dobsonian Telescope #9702 $499.99
Orion® EON 115 ED Triplet Apochromatic Refractor Telescope #10087 $1,799.99
Orion® GoScope II 70mm Refractor Travel Moon Kit #10034 $89.99
Orion® Starshoot™ Pro Mono Astrophotography Camera #52031 $399.99
Orion® Starblast™ 90mm AZ Telescope & Beginner Barlow Kit #27300 $309.99
Orion® SkyQuest™ XT8 PLUS Dobsonian Reflector #8974 $519.99
Orion® Awesome AutoGuider Telescope Package #24770 $429.99
Orion® StarShoot™ G3 Deep Space Color Imaging Camera #53082 $420.23
Orion® XT6 Classic Dobsonian Telescope & Beginner Barlow Kit #27193 $359.99
Orion® SkyScanner™ 100mm Tabletop Reflector Telescope #10012 $123.59
Orion® ED80T CF Triplet Apochromatic Refractor Telescope #9534 $949.99
Orion® Planetary Observing Guide Kit #25703 $49.99
Phone not included
Orion® SteadyPix™ Universal Smartphone Telescope Photo Mount #5337 $47.27
Shopping has never been easier.
To learn more about our products and see a larger assortment, check out the digital eCatalogs on our website!
Retail prices shown are current as of 10/12/15 from Orion. Prices are subject to change without notice. Please check OrionTelescopes.com for the most current pricing. Dealer pricing and/or promotions may vary.
OrionTelescopes.com
Shop Orion On-the-Go. Easy Access right on your Smartphone.
Orders: (800) 447-1001
Customer Service: (800) 676-1343
*We only collect sales tax in CA & PA. See web site for details.

FROM THE **EDITOR**

BY DAVID J. EICHER

The biggest story of all

In this issue, the editors take pride in presenting a popular annual feature showcasing the biggest stories of the year in astronomy. As you no doubt can guess, Pluto and the exploration of comets figure heavily into this year's equation. As the flood of new information rains over us, we sometimes ought to remind ourselves about the guiding quest that drives much of this science: to understand how rare or how common life is in the cosmos.

Are we alone in the universe? Spacecraft missions concentrate on Mars because of the Red Planet's relative similarity to Earth and the existence of water there, leading to the possibility of microbial life. The rapidly growing cottage industry of finding and studying extrasolar planets looks forward to detecting Earth analogs that may also reveal atmospheric signatures of living beings. The discovery of life elsewhere in the cosmos would certainly mark one of the most incredible moments in human history.

Of course, we know of only one example of life in the universe, right here on Earth. In the minds of some, that means the odds of life being an extremely rare thing in the cosmos are high — at least intelligent life. They point back to the idea that Italian physicist Enrico Fermi raised in 1950: "If the universe contains life, then where is it? Why hasn't life showed up on our doorstep?" The so-called Fermi Paradox still stands as a fair question. But the odds of life in the universe are staggeringly large, in the minds of astronomers and cosmologists.

The universe contains at least 100 billion galaxies, and probably considerably more because inflation theory means we are not seeing the whole universe that exists. And let's consider the number of stars in a galaxy like the Milky Way, about 400 billion. Let's set inflation aside. From what we see of star systems near the Sun, planetary systems appear to be common, and we are seeing the first glimpses of planets within the habitable zones of their suns — the areas in which water would be a liquid. From what we know, water is absolutely essential for life.

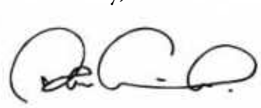
Astronomers currently believe that something like 70 or 80 percent of stars have planets. With 100 billion galaxies in the universe and, to play it conservatively, let's assume roughly 100 billion stars on average for each galaxy, that works out to 10,000 billion billion stars in the universe, and roughly 10^{22} planetary systems, or 8,000 billion billion.

Do we really believe that we are the only planet on which life exists? Or the only planet on which a civilization exists with so-called intelligent life? The odds seem against that.

But we just don't know. Perhaps in decades to come, we'll discover microbes by sampling aquifers on Mars, subsurface oceans in Europa or Enceladus, or methane-rich lakes on Titan. Perhaps we'll record a high-precision spectrum of a habitable zone exoplanet that will convince us life must exist there. Perhaps we will receive an alien signal from one of the ongoing SETI searches.

Until that magic moment of discovery comes, if indeed it does, this quest will always be one that drives human intellect forward.

Yours truly,



David J. Eicher
Editor

Follow the Dave's Universe blog:
www.Astronomy.com/davesuniverse
Follow Dave Eicher on Twitter: **@deicherstar**

Astronomy

Editor David J. Eicher
Art Director LuAnn Williams Belter

EDITORIAL
Senior Editors Michael E. Bakich, Richard Talcott
Production Editor Karri Ferron
Associate Editors Eric Betz, Korey Haynes
Editorial Associate Valerie Penton

ART
Senior Graphic Designer Chuck Braasch
Illustrator Roen Kelly
Production Coordinator Jodi Jeranek

CONTRIBUTING EDITORS
Bob Berman, Adam Block, Glenn F. Chaple, Jr., Martin George, Tony Hallas, Phil Harrington, Jeff Hester, Liz Kruesi, Ray Jayawardhana, Alister Ling, Steve Nadis, Stephen James O'Meara, Tom Polakis, Martin Ratcliffe, Mike D. Reynolds, Sheldon Reynolds, Erika Rix, Raymond Shubinski

EDITORIAL ADVISORY BOARD
Buzz Aldrin, Marcia Bartusiak, Timothy Ferris, Alex Filippenko, Adam Frank, John S. Gallagher III, Daniel W. E. Green, William K. Hartmann, Paul Hodge, Anne L. Kinney, Edward Kolb, Stephen P. Maran, Brian May, S. Alan Stern, James Trefil

Kalmbach Publishing Co.
President Charles R. Croft
Vice President, Editorial Kevin P. Keefe
Senior Vice President, Sales & Marketing Daniel R. Lance
Vice President, Consumer Marketing Nicole McGuire
Editorial Director Diane M. Bacha
Corporate Art Director Maureen M. Schimmel
Art and Production Manager Michael Soliday
Corporate Advertising Director Ann E. Smith
Single Copy Specialist Kim Redmond

ADVERTISING DEPARTMENT
(888) 558-1544
Advertising Sales Manager Steve Meni
Advertising Sales Representative
Dina Johnston, djohnston@kalmbach.com
Ad Services Representative
Christa Burbank, ads@astronomy.com

RETAIL TRADE ORDERS AND INQUIRIES
Selling *Astronomy* magazine or products in your store:
Phone (800) 558-1544, Press 3
Outside U.S. and Canada (262) 796-8776, ext. 818
Fax (262) 798-6592
Email tss@kalmbach.com
Website www.Retailers.Kalmbach.com

CUSTOMER SALES AND SERVICE
Phone (800) 533-6644; **Fax** (262) 796-1615
customerservice@kalmbach.com

SPECIAL EMAIL ADDRESSES
Ad Sales adsales@astronomy.com
Ask Astro askastro@astronomy.com
Books books@astronomy.com
Letters letters@astronomy.com
Products products@astronomy.com
Reader Gallery readergallery@astronomy.com

Editorial phone: (262) 796-8776; advertising: (888) 558-1544; customer service & sales: (800) 533-6644; outside the U.S. and Canada: (262) 796-8776, ext. 421, Monday through Friday, 8:30 A.M. to 4:30 P.M. CT, Fax: (262) 796-1615; Email: customerservice@kalmbach.com. Please include your name, mailing address, and telephone number with any correspondence.

Printed in the U.S.A. Allow 6 to 8 weeks for new subscriptions and address changes. Subscription rate: single copy: $5.99; U.S.: 1 year (12 issues) $42.95; 2 years (24 issues) $79.95; 3 years (36 issues) $114.95. Canadian: Add $12.00 postage per year. Canadian price includes GST, payable in U.S. funds. All other international subscriptions: Add $16.00 postage per year, payable in U.S. funds, drawn on a U.S. bank. Expedited delivery service surcharges: Domestic first class $30/yr; Canadian air $30/yr; International air $60/yr. BN 12271 3209 RT. Not responsible for unsolicited materials.

Follow *Astronomy*
www.twitter.com/AstronomyMag
www.facebook.com/AstronomyMagazine
plus.google.com/+astronomymagazine

Alliance for Audited Media
KALMBACH PUBLISHING CO.
Please Recycle This Magazine

Real Telescopes
+ Real Elves*
+ Real Experience
= Really Good Holiday Shopping Advice
OPT
Santa not only keeps a list of every good boy and girl, but knows what each of them wants!
Has your favorite astronomer left you scratching your noggin?
Rejoice! OPT's elves are here to help.
With more than 6,500 toys to choose from, and the experience to dash you through to the right ones, we'll merrily help you be the perfect Santa.
*OPT's real human employees. No elves were harmed in the production of this ad.
OPT
...AND MUCH, MUCH MORE!
OPTtelescopes.com | 800.483.6287

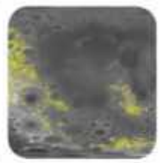
QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES>>

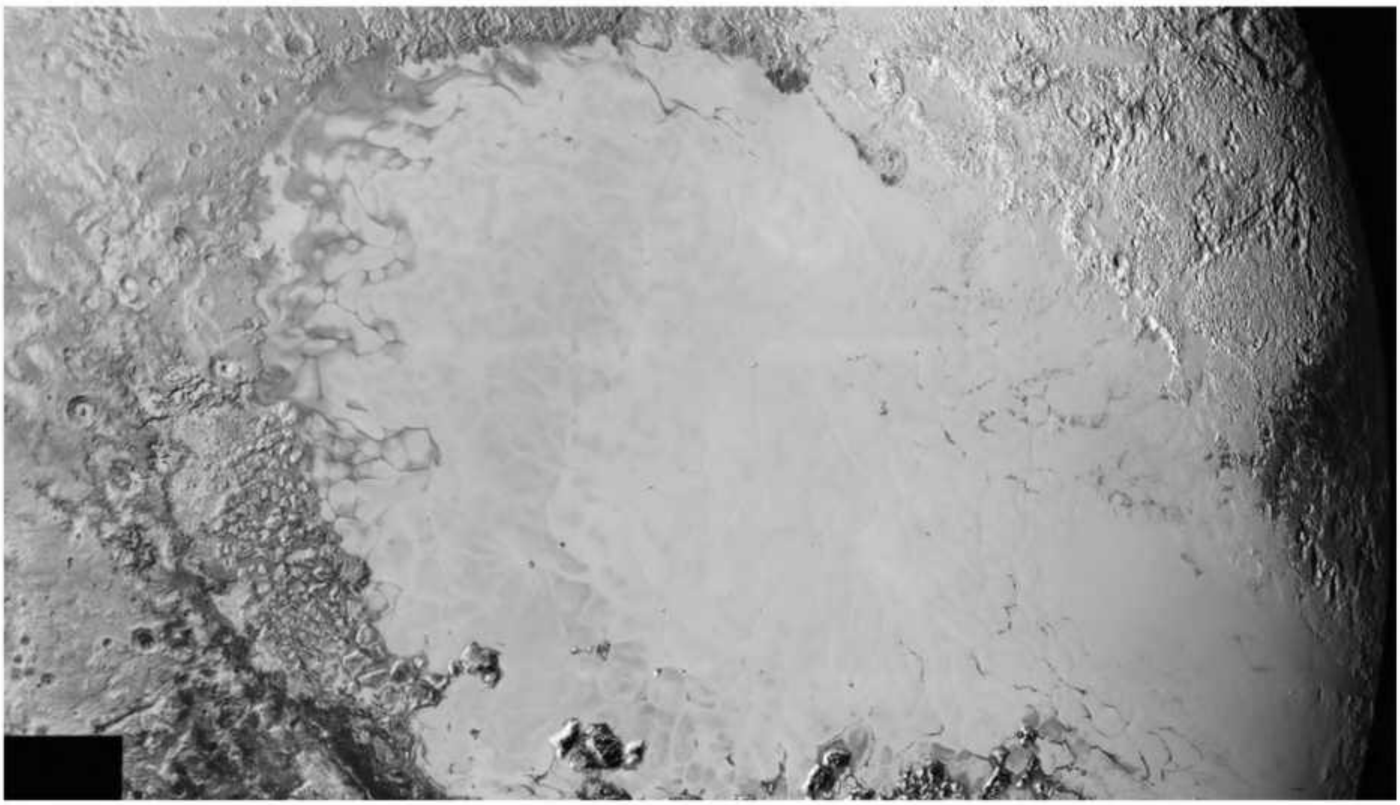
TRENDING TO THE TOP

ICE RING
NASA's Cassini spacecraft showed scientists that particles in Saturn's outermost main ring are likely solid ice instead of fluffy snowballs.



SHATTERED FACE
The Moon's farside highlands are literally as fractured as possible. Asteroids completely shattered its upper crust 4 billion years ago.

BABY PLANETS
Nearby red dwarfs with planet-forming disks give astronomers a peek at how planet formation might work around stars smaller than our Sun.



NASA/JHUAPL/SwRI (PLUTO); NASA/JPL/SSI (ICE RING); SODERBLOM ET AL., 2015 (SHATTERED FACE); NASA/JPL-CALTECH/T. PYLE/SSC (BABY PLANETS)

Incredibly complex forms and amazing variety exist on the frozen surface of Pluto, as revealed by the New Horizons spacecraft during its July 14, 2015, close encounter.

SNAPSHOT

Beyond belief on Pluto

If you have any interest in the solar system, sit back and relish this year. We've witnessed the highest-resolution views of a comet ever, courtesy of the Rosetta mission, Ceres, and now the image of Pluto in our anxious minds is coming alive, pixel by pixel.

The latest round of images sent back by the New Horizons spacecraft, which arrived in early September, reveals worlds that are far more varied than even the initial pictures suggested.

This synthetic perspective view, based on the highest-resolution images yet returned, depicts Pluto from a distance of some 50,000 miles (80,000 kilometers). It looks down on the planet's equatorial area, aimed northeast over the dark, cratered "Cthulhu" region, toward the bright icy plains informally called Sputnik Planum.

This image spans some 1,100 miles (1,800km) across and reveals craters, plains, ridges, wrinkled terrain, and what appear to be blocks of hard-frozen ice shaped by forces from a variety of directions.

It is an incredible, mind-blowing scene!

Wherever he is, Clyde Tombaugh is smiling. — **David J. Eicher**

STRANGE**UNIVERSE**

BY BOB BERMAN

Marketing the cosmos

There's a fine line between generating buzz and spreading misinformation.

Every day brings astronomy news. What grabs attention is the headline. Those big letters at the top of the page pull you in. But have you noticed how headlines have been changing?

It sometimes starts with academic, corporate, and governmental agencies that crave media attention. Public awareness brings them business or helps get them funded. So nearly everyone wants major newspapers and Internet sites to carry their event or discovery.

There's lots of competition. Countless scientific agencies, private space companies, universities, and research facilities send out daily press releases. Editors of mass media entities wade through a steady stream. They disseminate only a tiny percentage, which is what you end up reading.

I'm a player in that ballgame. At Slooh.com, we always try to get the media interested in our upcoming webcasts. In the old days, we merely announced ahead of time that we'd be streaming a meteor shower with low-light video cameras or using our Canary Island telescopes for live views of some comet. But a few years ago, we got wise. We realized that more of the mass media would focus on an event if we gave it a catchy headline. When announcing last July's close approach of asteroid 2011 UW_{158}, we called it the "5.4 Trillion Dollar Asteroid." That's the value of the platinum it may contain. Our show included me interviewing the president of Planetary Resources, the company that hopes to mine that planetoid. Nothing phony about any of it. But the catchy headline garnered lots of attention.

And instead of merely announcing this past September's lunar eclipse, *Astronomy* magazine's cover called it the "Eclipse of the Super Moon." That article accurately and candidly discussed the recent explosion of media hype of sky events and how they sensationalize astrophenomena that professional astronomers know to be subtle or even unobservable.

"Near miss by an asteroid" is another universal attention-grabber because people worry about impacts, and tying astronomy to personal paranoia is one key to generating interest. The point? The art of marketing now often envelops science.

NEARLY EVERYONE WANTS MAJOR NEWSPAPERS AND INTERNET SITES TO CARRY THEIR EVENT OR DISCOVERY.

It can easily create misinformation. Last July, the NASA Kepler folks found yet another exoplanet. Researchers had already found thousands. Our Milky Way Galaxy might boast more than 20 billion Earth-like worlds in orbits where liquid surface water could exist. So what could justify a front page *New York Times* story about finding yet another one, one that's *less* Earth-like than previous discoveries?

Packaging, that's what. The Kepler media people issued a press release calling their newly found world "Earth's bigger, older cousin." Then the news media went further, calling it "Earth 2.0." Catchy. It made headlines around the world. Unfortunately, some news outlets mistakenly called it an "Earth twin" or "the first found beyond our solar system."

In truth, that particular exoplanet, named Kepler-452b, has five times the mass of Earth, a 50 percent larger diameter, and twice our gravity — not remotely an Earth twin. Indeed, it's a coin toss whether it even has a rocky surface as opposed to being a gas world like Neptune. It really didn't deserve the front page. But the "Earth 2.0" phraseology resonated among editors looking for a news hook.

The public adores the notion of "another Earth," and the hope of finding E.T. life is the engine driving that train. You can thus count on many more hyped-up headlines surrounding routine exoplanet discoveries. The honest-to-goodness *major* discoveries in that area were: a) the first exoplanet detected around a sunlike star, 51 Pegasi, two decades ago, and b) finding thousands more of all kinds, letting us know there are many billions in our galaxy.

Those are the important takeaways. As for the future, truly sensational news would be discovering either radio signals signifying intelligence or at least free oxygen in an exoplanet's atmosphere, which would indicate plant life. Nothing else matters very much. Having Earth's mass and a comfortable orbit makes for a good storyline because it makes readers imagine an Earth lookalike. In reality, those characteristics may or may not mean there's life. Or even any resemblance to our world. Millions of planets will meet those criteria. But then what? We can't go for a close-enough look, not for centuries to come.

Anyway, if finding E.T. is important, life-friendly oceans might lurk just under the ice on several bodies here in our solar system. The easiest to examine is probably on Jupiter's moon Europa. Shouldn't we fast track a lander to check it out? We could get there in three years with today's rocketry. Care to guess how many such life-probing missions are being built?

Zero.

Those saltwater seas need media attention, which would ignite public interest, jumpstart funding, and get NASA moving beyond a few flybys and onto the surface. Europa's warm ocean desperately needs marketing assistance. First hype requirement: a catchy name.

Got an idea?

Contact me about my strange universe by visiting **http://skymanbob.com.**

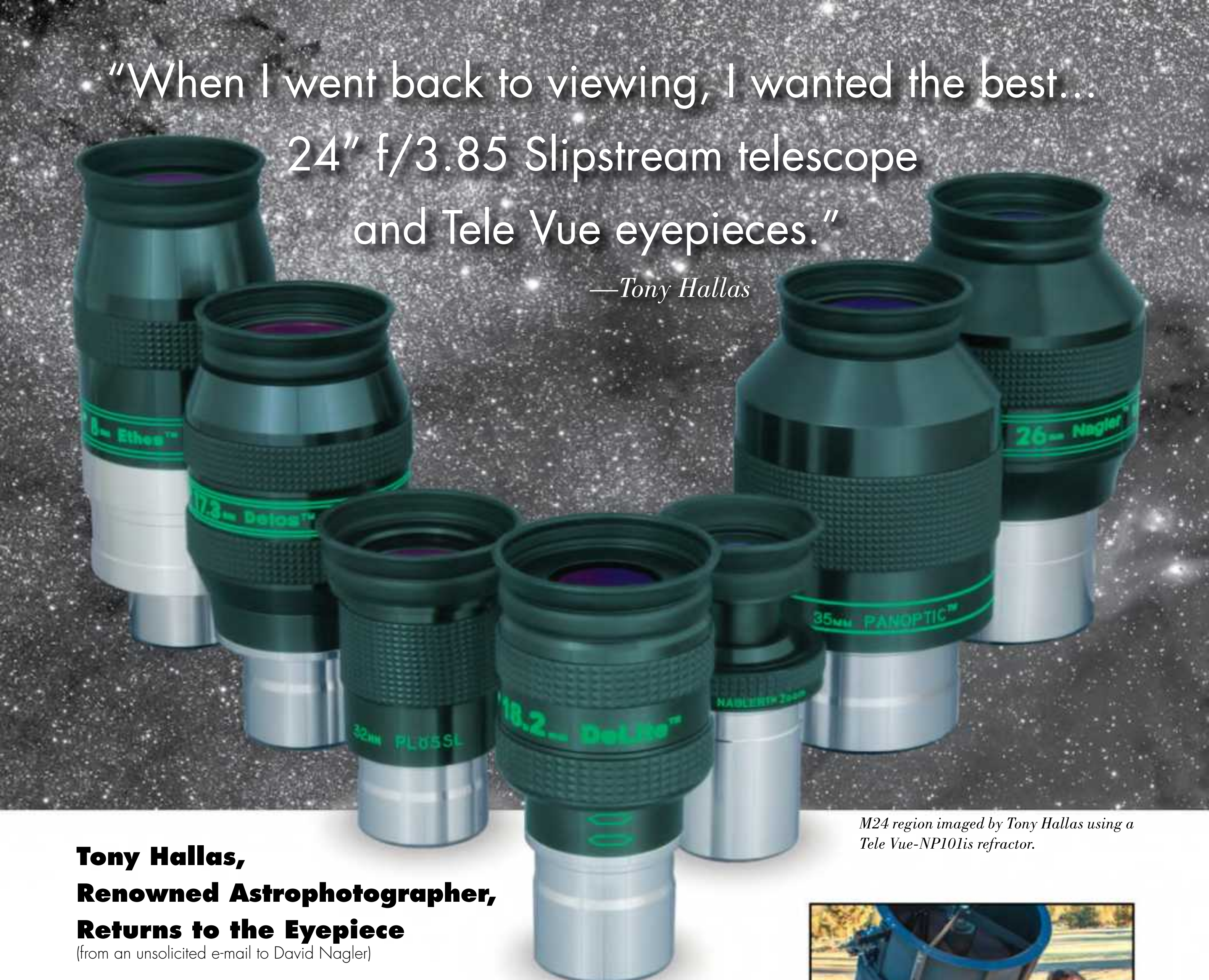
FROM OUR INBOX

Thanks for the welcome addition

I've been amazed at Bob Berman's ability to make astronomy fun, but Jeff Hester is adding a new dimension to your magazine. I have thoroughly enjoyed every one of Hester's columns. Thank you for bringing him onto your team. I look forward to his column every month.— **Michael Schimpf,** Pacific Grove, California

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman.**



M24 region imaged by Tony Hallas using a Tele Vue-NP101is refractor.

Tony Hallas, Renowned Astrophotographer, Returns to the Eyepiece

(from an unsolicited e-mail to David Nagler)

Hi David and Al,

Although I am still active in imaging, I have decided to go back to viewing and have taken possession of a new 24" f/3.85 Slipstream telescope from Tom Osypowski. You will be happy to know that I have acquired a treasure trove of TeleVue eyepieces to complement this telescope, specifically: 26 and 20mm Nagler Type 5, 17.3, 14, 10, 6, 4.5mm Delos, Paracorr Type 2, and 24mm Panoptics for binocular viewing. After using a Delos, "that was all she wrote;" you have created the perfect eyepiece. The Delos eyepieces are a joy to use and sharp, sharp, sharp! I wanted to thank you for continuing your quest to make the best eyepieces for the amateur community. I am very glad that you don't compromise ... in this world there are many who appreciate this and appreciate what you and Al have done for our avocation. Hard to imagine what viewing would be like without your creations.

Best,
Tony Hallas

Tony with his Tele Vue eyepiece collection awaits a night of great observing at his dark-sky site.

TeleVue® Visionary

32 Elkay Dr., Chester, New York 10918 (845) 469-4551. televue.com

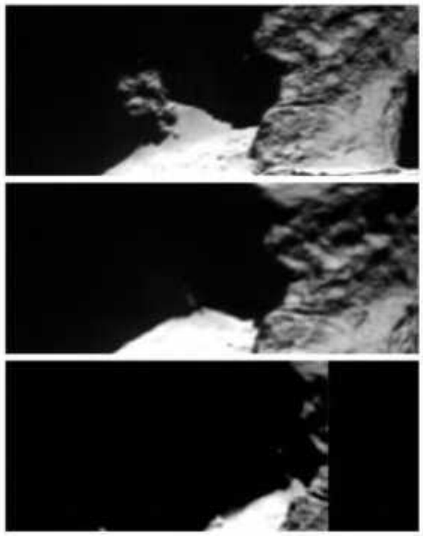
 STAR TWINS. Astronomers found a new way to measure cosmic distances: in sets of stars with nearly identical spectra where one star has an accurate distance measurement, the twin's distance can be easily calculated by comparing its brightness to the first.

ROSETTA SPIES WATER CYCLE ON 67P

Comet 67P/Churyumov-Gerasimenko is an active place, as the European Space Agency's Rosetta spacecraft has shown over the last year and a half. Most recently, scientists announced September 23 in *Nature* that the comet experiences a daily water-ice cycle on and near its surface. "We found a mechanism that replenishes the surface of the comet with fresh ice at every rotation; this keeps the comet 'alive,'" says Maria Cristina De Sanctis, lead author of the study.

Comet 67P takes just over 12 hours to complete one rotation, with different regions entering in and out of sunlight during this time. The researchers focused on one area in particular near the comet's "neck" called the Hapi region. They saw that ice was present on the comet's surface when it was shaded but rapidly disappeared — turning directly from ice to water vapor (or sublimating) — when exposed to sunlight. The replenishment happens because the layers just under the comet's surface remain warm even after the sunlight fades, and so subsurface water ice continues to sublimate through the comet's porous upper layers at "night," coating the surface with a fresh layer of ice for the next day.

Comet 67P reached perihelion, its closest approach to the Sun, on August 13, and is now headed back out to beyond the orbit of Jupiter. — **Korey Haynes**



ESA/ROSETTA/VIRTIS/INAF-IAPS/OBS DE PARIS-LESIA/DLR; M.C. DE SANCTIS ET AL. (2015)

WATER WORKS. As Comet 67P rotated, the same region with different illuminations showed scientists water ice appearing and disappearing.

A YEAR IS A YEAR IS A YEAR?

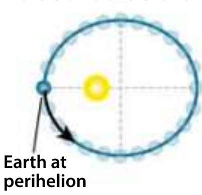
REVOLUTION. Earth orbits the Sun in one year. Believe it or not, however, a number of different years exist. Each serves a different astronomical purpose. *ASTRONOMY*: MICHAEL E. BAKICH AND ROEN KELLY

The word "annual," meaning yearly, comes from the Latin word for year, *annus*.

FAST FACT

Anomalistic year

365.259636 days



The time Earth takes to travel from one perihelion (closest to the Sun) to the next.

Draconitic year

346.620075883 days

Sometimes called the eclipse year, the time it takes for the Sun to move from one lunar node (where the Moon's path intersects the Sun's) to the same lunar node from our perspective.

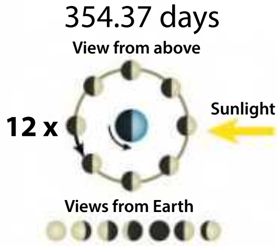
Julian year

365.25 days

The time period most people think of as normal, with three years of 365 days and a fourth of 366.

Lunar year

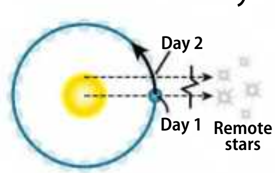
354.37 days



The combined time of 12 cycles of lunar phases.

Sidereal year

365.256363004 days



The time Earth takes to make one orbit relative to the stars.

Tropical year

365.24219 days

The time it takes for the Sun to travel 360° along the ecliptic, its apparent path through our sky.

BRIEFCASE

CHATTER INCREASES IN MILKY WAY'S BLACK HOLE

The supermassive black hole at the heart of our galaxy, known as Sagittarius A*, is relatively quiet compared to other galaxies. However, the activity level has recently ramped up, according to observations made by three orbiting X-ray space telescopes. As a suspected gas cloud circled our galactic center, the rate of X-ray flares increased tenfold from the one every 10 days previously. Astronomers aren't certain how unusual the action is because this sort of long-term monitoring has never been done before.

•

BLACK HOLE PAIRS LESS COMMON THAN THOUGHT

In 1916, Albert Einstein predicted gravitational waves as a consequence of his new general theory of relativity. And in recent years, scientists have searched for signs of them coming from pairs of supermassive black holes circling each other in the centers of galaxies. But new research published using the Very Large Array radio telescope shows that these mighty duos might be less common than astronomers thought, potentially making it tougher to find gravitational waves. In a study of 52 candidates, only 11 ended up being black hole pairs.

•

ENCELADUS HAS A GLOBAL OCEAN

The finds keep coming from NASA's Cassini mission at Saturn. In September, astronomers announced new evidence that the ringed planet's icy moon Enceladus has more than just a regional sea beneath its crust — it actually has a global liquid water ocean. Years of photos were compiled to precisely track the moon's wobble and determine that Enceladus' rotation is best explained by a global body of water. — **Eric Betz**

25 years ago in *Astronomy*

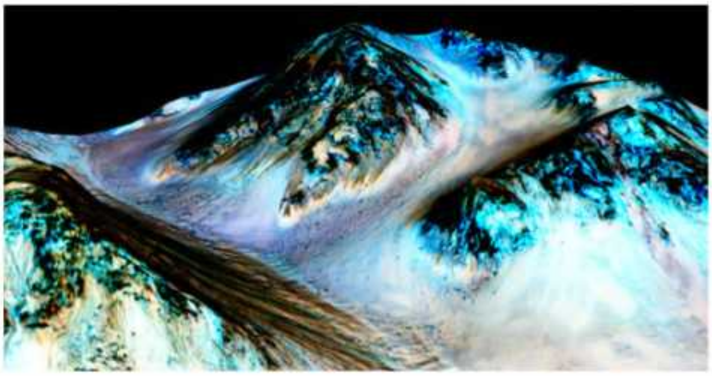
Current Editor David J. Eicher took readers on a photo tour of Venus courtesy of the Magellan spacecraft's fresh imagery in January 1991. Twenty-five years later, new revelations are still coming in from Earth's neighbor, as the Venus Express mission wrapped up its eight-year mission in 2015.

10 years ago in *Astronomy*

In the January 2006 issue of *Astronomy*, Francis Reddy covered the top stories from the previous year. Number one went to the joint NASA/European Space Agency orbiter Cassini and its lander, the Huygens probe, which touched down on the surface of Saturn's moon Titan. — **E. B.**

NITROGEN FIND. Astronomers used a combination of new models and old data from EPOXI, NASA's repurposed Deep Impact mission, to prove they could detect nitrogen — Earth's atmosphere's main component — in an alien atmosphere.

Untangling the mysteries of Mars' water



NASA/JPL-CALTECH/UNIV. OF ARIZONA

WET MARS. The dark, narrow streaks visible in the above image were thought to indicate current water flowing on Mars, and new spectral evidence confirms it.

Astronomers are learning more about water on Mars, both in the past and present. NASA's Mars Reconnaissance Orbiter (MRO) confirmed that liquid water persists on Mars' surface even today. It did this by studying the composition of dark features called recurring slope lineae, first observed in 2010. While scientists thought then that the flows were signs of current liquid water on Mars, MRO only recently confirmed in the streaks signatures of hydrated minerals, meaning minerals that formed in the presence of liquid water. These perchlorates, as they are known, can keep water liquid even at very cold temperatures (–94° F or –70° C). Multiple Mars missions have observed perchlorates, but this is the first time they have been seen in conjunction with the recurring slope lineae that indicate current water. The researchers published their results September 28 in *Nature Geoscience*.

This flowing water is still a small amount, more like dampened soil than cascading streams. Yet in its distant past, Mars must have streamed with water, evidenced by the large flood channels preserved on its surface. Scientists are learning more about this ancient water as well. Researchers published September 8 in *Nature Scientific Reports* that contrary to previous theories, this ancient flooding was not the result of a global water table coming free, but rather regional underground frozen deposits melting and flooding the martian surface. And, because both the freezing and melting processes were regional, points out Alexis P. Rodriguez, lead author of the study, it is possible that large reservoirs of water ice remain trapped under the martian surface.

The biggest question, of course, is why Mars lost all its water in the first place. Astronomers know that to host the large amounts of water the Red Planet previously held, it must have had a thicker atmosphere, but the details of how it lost that atmosphere remain vague. Researchers expected that the martian surface should have trapped vast stores of carbon that used to make up the planet's atmosphere. But researchers published online August 21 in *Geology* that far too little carbon exists in the planet's carbonate minerals today to account for the expected atmosphere of the past. They suggest instead that Mars lost its atmosphere upward to space rather than hoarding it via mineral sequestration. They also hypothesize that the loss occurred earlier than previously thought, so that Mars' atmosphere was already thinning even when rivers still flowed to form the now-dry valleys seen on the Red Planet today. **— K. H.**

The Milky Way and Andromeda have similar litters of stars

COUNTING STARS. Citizen scientists worked to identify star clusters where astronomers could measure the initial mass function, or how many stars of each size are produced in a wave of star formation. NASA/ESA/J. DALCANTON, B.F. WILLIAMS, L.C. JOHNSON (UW)/PHAT TEAM/R. GENDLER

Hundreds of Hubble Space Telescope images and nearly two million image classifications by citizen scientists combined to reveal in exquisite detail the kinds of stars the Andromeda Galaxy (M31) gives birth to. When a nebula's clouds of gas and dust condense into stars, astronomers see them produce a few giant hot stars, some medium Sun-like stars, and many tiny red dwarfs. The exact breakdown of star size and number produced in a stellar nursery is known as the "initial mass function" (IMF), and scientists want a detailed census so they can better understand star formation and galaxy evolution even when they are too far away to measure individual stellar populations. The only places where astronomers can observe these individual star-forming regions well enough to measure the IMF have been within our own Milky Way Galaxy — until now.

New ultra-high-resolution images of M31 allowed researchers to measure the IMF not just in our immediate neighborhood, but 2.5 million light-years away. They compared populations across Andromeda, but found the same IMF everywhere, and though it matched previous measurements closer to home, some of the brightest stars appeared less abundant than expected. The biggest stars explode in supernova events and contribute heavy elements to the universe — the kind that make up most of our bodies — so knowing how quickly the cosmos grew its metals is crucial to understanding cosmic evolution. The research appeared June 20 in *The Astrophysical Journal.* **— K. H.**

QUICK TAKES

RARE PAIR
Researchers found a pair of black holes orbiting with a separation only slightly larger than our solar system and set to collide in less than a million years.

LISA IS READY
LISA Pathfinder, a test mission for the planned gravitational wave observatory eLISA, completed all tests September 1 and waited only for launch day.

WEAR AND TEAR
A researcher shot hydrogen atoms at common minerals to simulate the solar wind's weathering of asteroids and other space rocks and learn how iron forms.

SMART PHONES
A Dutch project distributed small devices that attach to smartphones so crowds of citizen scientists could measure air pollution anywhere with cloud-free skies.

MINI MIGHT
Astronomers discovered that a small dwarf galaxy can still produce prodigious star formation with the help of compact molecular clouds hidden inside.

MAGNETIC STARS
A Canadian Ph.D. student found a rare pair of massive stars. Magnetic fields are rare in massive stars and in close pairs, yet both members of this binary system host strong magnetic fields.

YOUNG MERGER
Most galaxy clusters grow from combining older galaxies, but astronomers spotted one cluster with extremely active star formation, showing it must be combining fresher members.

NEXT STAGE
The upcoming Dark Energy Spectroscopic Instrument (DESI), which will answer some of cosmology's most pressing questions, received its next stage of approval from the Department of Energy. **— K. H.**

FOR**YOUR**CONSIDERATION

BY JEFF HESTER

Not science fiction

Three cheers for multiverses!

When quantum mechanics was young, scientific giants of the day went toe to toe over the unquestionably bizarre, almost preposterous new theory. For Albert Einstein, wave functions and indeterminate outcomes just didn't smell right. He famously declared, "God does not play dice!" Niels Bohr is said to have responded with equal bravado, "Albert, stop telling God what to do!"

For those acquainted with the tumultuous birth of quantum mechanics, today's debates over the existence of multiple universes might inspire a feeling of déjà vu. Physicists like Stephen Hawking and Max Tegmark see multiverses as unavoidable. Others like Peter Woit counter that the idea is not only wrong, but a threat to science itself. To multiverse or not to multiverse — that is the question. This is fun stuff!

Multiverses may seem outlandish, but they are hardly misbegotten brainchildren of demented theorists. From the physics of the Big Bang, to the flatness of the observable universe, to the mass of the Higgs boson and a paucity of particles seen at the European particle physics lab CERN's Large Hadron Collider, to the ambiguous fate of Schrödinger's cat, multiverses arise from promising efforts to fill gaping holes in the foundations of physics and cosmology.

If multiverses are such a powerful idea, why do some people wish them a speedy and ignominious death? While there are certainly outstanding scientific questions, some of the most passionate critics focus on more philosophical concerns. In particular, some insist that absent falsifiable predictions, multiverses have no place in science at all.

I understand that concern. If you've read my past columns, you know that falsifiability is a *really* big deal with me. Scientific knowledge is built on testing falsifiable predictions. But that is not the same thing as saying that everything we know can be or needs to be tested directly.

Quoting Alfred North Whitehead: "There are no whole truths; all truths are half-truths. It is trying to treat them as whole truths that plays the devil." When it comes to falsifiability, like it or not, gray areas exist. Scientists routinely accept necessary consequences of well-tested theories, regardless of whether those consequences are independently testable. Cosmology is a case in point.

The cosmological principle is the bedrock of our understanding of the structure and evolution of the universe. Simply put, the cosmological principle says that there is nothing special about our place in the universe. Yet that statement is patently absurd. We live in a very special place in the *observable* universe; we are right at its center.

The whole science of cosmology rests on the untestable claim that our observable universe lies buried within a vastly larger universe filled with stars and galaxies that we can never see. We know those galaxies are there because well-tested theories rely on them. Multiverses may be different in degree, but they are no different in principle. Sorry, but if you want to restrict science to things that we can directly observe, you are out of luck. That ship has sailed.

The fact that we can't see multiverses doesn't mean they don't exist, nor is talking about them a threat to science. Karl Popper, the father of falsifiability himself, noted that unfalsifiable statements can still be true, and even if not true can still be scientifically useful.

David Deutsch is a pioneer in the emerging science of quantum information. He says that everything he does depends on one particular multiverse, Hugh Everett's "many-worlds interpretation" of quantum mechanics. Regardless of whether it exists, without the *idea* of Everett's multiverse, quantum computers, quantum encryption, and quantum teleportation might have yet to be invented.

The philosophical implications of multiverses are profound. From the moment Copernicus dislodged Earth from the center of creation, scientific progress has gone hand in hand with an ever-expanding concept of the cosmos. Multiverses represent that journey's ultimate culmination.

In most multiverse theories, every universe that can exist does exist, has always existed, and always will exist. The question of, "why *this* universe" is meaningless. Of course we find ourselves in a universe suspiciously well suited for life. Where else could we be? Einstein could be right. Perhaps God does not play dice, but neither does he choose!

Demanding that existence limit itself to what humankind can directly observe is pretty egotistical, a bit like the medieval insistence that Earth is the center of all things.

Any given roll of the die may be unlikely, but roll enough of them and every possible outcome grows not only possible, but assured. ©ISTOCK.COM/JUMBO2010

Scientifically, the statement "multiverses exist" deserves to be on equal footing with the statement "multiverses do not exist." There is no *a priori* reason to prefer one statement over the other.

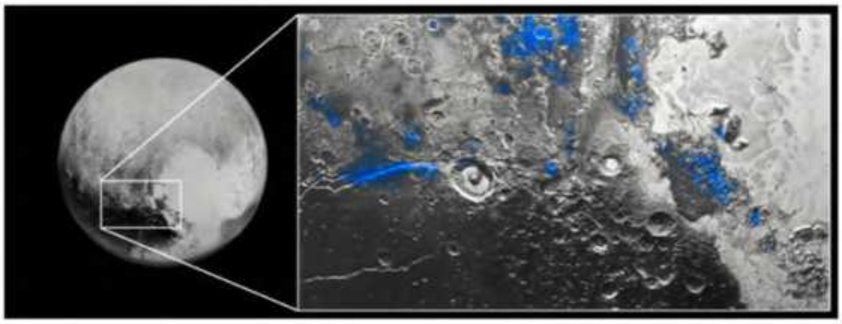
Can we observe multiverses? That's the wrong question. The right question is whether theories that rely on multiverses are more or less successful than theories that do not. Putting it differently, the statement "multiverse theories will make more interesting and correct predictions than theories without multiverses" is itself a testable prediction. On that basis, the scientific case for multiverses could prove very compelling, indeed.

Jeff Hester is a keynote speaker, coach, and astrophysicist. Follow his thoughts at **jeff-hester.com.**

BROWSE THE "FOR YOUR CONSIDERATION" ARCHIVE AT **www.Astronomy.com/Hester.**

 ABSENT E.T. Alien life on advanced galactic scales — so-called Kardashev Type III civilizations — appears to be absent from our local universe, as astronomy surveys searching for them have turned up nothing.

Pluto surprises with blue skies, red water



ICY SHELL. Pluto has ample water, but its shell is mostly more volatile ices. NASA now says that small surface water ice areas are also common. NASA/JHUAPL/SwRI

Blue skies surround a dark and gloomy world 3 billion miles (5 billion kilometers) from Earth.

The first color photos of Pluto's atmosphere trickled back from NASA's New Horizons spacecraft in October, giving astronomers fresh evidence for how the dwarf planet's thin veil works.

"Who would have expected a blue sky in the Kuiper Belt? It's gorgeous," says New Horizons Principal Investigator Alan Stern of the Southwest Research Institute (SwRI) in Boulder, Colorado.

On Earth, our blue skies are caused by light scattering off nitrogen and oxygen molecules in the atmosphere. But on Pluto, scientists suspect the Sun's faint light scatters off soot-like particles known as tholins, which form as ultraviolet light breaks down and ionizes molecules like methane and nitrogen. The actual particulates are likely gray or red, but the scattering makes them appear blue. As these tholins fall to the surface, they grow by interacting with volatile ices and ionized molecules, eventually becoming red.

New Horizons data have already shown Pluto has an unexpectedly low surface pressure of just 1/100,000 that of Earth — about half of the expected value. That indicates much of its atmosphere already has collapsed as Pluto moves out in its elliptical orbit.

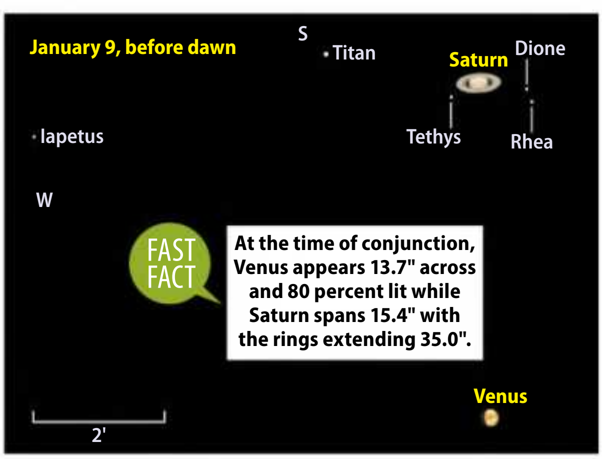
BLUE RING. Pluto's blue skies brought smiles to the New Horizons team in October. NASA/JHUAPL/SwRI

In October, the spacecraft also found the chemical fingerprints of water ice on the surface. Water is abundant on Pluto, but its shell is largely covered by nitrogen and methane.

"Understanding why water appears exactly where it does, and not in other places, is a challenge that we are digging into," says New Horizons scientist Jason Cook of SwRI.

Curiously, the regions richest in water ice are also red. "We don't yet understand the relationship between water ice and the reddish tholin colorants on Pluto's surface," says Silvia Protopapa, of the University of Maryland, College Park. **—E. B.**

WHEN VENUS MEETS SATURN



CLOSE ENCOUNTER. Venus makes a spectacularly close approach to Saturn before dawn January 9. This chart shows the scene at 4h UT (11 P.M. EST on the 8th), when Venus lies 5' due north of the ringed planet. By the time the pair rises around 5 A.M. local time in North America, the two stand about three times farther apart — still close enough that both show disks in a single telescopic field of view. The two planets haven't appeared this close since 2006. *ASTRONOMY*: RICHARD TALCOTT AND ROEN KELLY

MARS OR BUST. NASA tested the Orion spacecraft's parachutes in 2012 by dropping it from a C-17 aircraft 25,000 feet above the Arizona desert. The space agency now says budget constraints will push back the first tests with crew onboard by two years. NASA

The long journey to Mars grows by 2 years

Despite the savvy NASA public relations campaign tied to the release of Ridley Scott's *The Martian*, America's beleaguered human spaceflight program still took a step back during September. The first launch to carry humans on NASA's new deep space crew vehicle has slipped until 2023 — nearly two years later than previously planned.

The slip isn't the program's first.

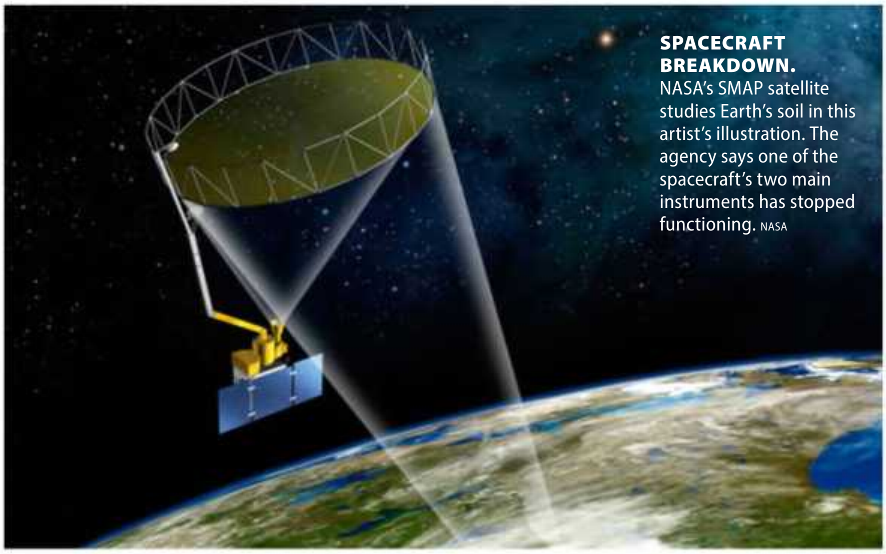
That crew vehicle, now known as Orion, was first announced in 2004 following the Space Shuttle *Columbia* disaster, as part of a program that would replace previous proposed space plane designs and return humans to the Moon "as early as 2015." The course was soon reimagined as the Constellation program, and then eventually canceled itself in 2009 after a review found it was underfunded and far behind schedule. But not long after, a compromise mission was announced that would keep Orion and instead send humans to an asteroid and on to Mars in the 2030s.

Then, in December 2014, Orion was finally launched for the first time and became the first crew-capable spacecraft launched beyond low-Earth orbit since Apollo. The rocket built to carry Orion, the Space Launch System, is due to see its first launch in 2018. And, following more tests, the two were set for an initial crewed launch in 2021.

But as NASA battles Congress to fully fund the private spacecraft it has contracted to supply the International Space Station, the agency announced September 16 that without its requested funds, Orion's first crewed launch could slip some 20 months.

Some in Congress called the delay a political tactic because NASA wasn't getting the funding it wanted, but the space agency says technical hurdles have cost Orion time as well. **— E. B.**

ASTRO**NEWS** **TORN APART.** Observers miss many tidal disruption events — black holes shredding stars — because the tattered material is hard to spot.



SPACECRAFT BREAKDOWN. NASA's SMAP satellite studies Earth's soil in this artist's illustration. The agency says one of the spacecraft's two main instruments has stopped functioning. NASA

Radar breaks on new Earth science orbiter

NASA's efforts to study our home planet were dealt a major blow in September when the agency acknowledged that its new Soil Moisture Active Passive (SMAP) spacecraft would never recover from a July "anomaly."

The orbiter's radar broke over the summer, leaving it to observe with its only other instrument, the radiometer.

That means the $1 billion satellite — launched in January 2015 — now can't carry out its complete science goals.

SMAP, the last of five NASA Earth science spacecraft launched in a year, was built to study our planet's soil and aid humanity's understanding of how the water, energy, and carbon cycles operate and interact.

Climate scientists refer to soil moisture as the tiny cog that connects larger gears, and by linking SMAP's data with those collected by NASA's Orbiting Carbon Observatory 2, they had hoped to better model future changes in Earth's climate.

SMAP was also built to provide modeling and real-time observations for everyone from fire and agricultural agencies to weather prediction centers forecasting droughts and floods.

A team of engineers spent months trying to resuscitate the radar, which worked for several months, before it was deemed a failure. NASA officials say the agency will continue using SMAP's radiometer, which can still provide useful data. — **E. B.**

SECRET**SKY**

BY STEPHEN JAMES O'MEARA

A tail of copper

Two views of the same meteor

On August 13, 2015, *Astronomy* Senior Editor Michael E. Bakich shared the experience of watching the Perseid meteor shower with his wife, Holley. Around 4h UT, they saw a magnitude –8 fireball that boasted a brilliant, 35°-long path.

"The coolest thing about it was the color," Bakich blogged on Astronomy.com. "It started as a classic lemon yellow, but the last 10° of its run took on a distinct coppery hue." Bakich wondered if this was a "true shift in the meteor's color or if the red and green cone cells in his eyes were fatigued with an overload of yellow."

Curiouser and curiouser

When we focus on a color for an extended time or if the source of color is exceedingly bright, our eyes' color-sensitive cone cells can become desensitized (fatigued), leading to an optical illusion called an afterimage — a lingering pseudo-image of the source but of the opposite color. Because the complement of yellow is blue, the copper color Bakich and his wife saw was not an afterimage.

However, an afterimage projected onto the color that stimulated it can alter the original color — a phenomenon known as successive contrast. As color-theory expert David Briggs of the National Art School in Sydney, Australia, explains, "Successive contrast resulting from adaptation is the actual explanation of the phenomenon sometimes mislabeled 'fatigue' of the eye."

When a blue afterimage is superimposed on yellow, the yellow turns … copper! Is this the end of the story?

The streaks on this page show the perceived colors of a meteor seen by Michael and Holley Bakich, who were observing north of Milwaukee, Wisconsin, and Deborah Carter and the author, observing in Maun, Botswana. The author asked Michael Bakich and Carter to select the color of the meteor trail from a color chart. The choices show a slight difference. ALL IMAGES: STEPHEN JAMES O'MEARA

When both choices appear against a similar dark background, however, they look even more like each other. These observations of the same meteor, taken some 8,200 miles (13,200 kilometers) apart, were a spectacular coincidence.

Adding the author's color selection shows that he saw a slightly redder trail, but he was looking away from the meteor toward a brighter part of the sky, so a contrast effect may explain the difference.

Shared experience

Around 4h UT on August 13, Deborah Carter and I saw a similarly long and bright Perseid fireball from Maun, Botswana — and the meteor was copper colored! The principal difference is that we saw the fireball against the bright blue of dawn, so contrast effects did not affect our cone cells as strongly. That's why high beams from a car do not overpower the eyes as much in the dawn as they do at night.

Curious, I asked Bakich and Carter to select from the same color chart the shade of copper they saw; I independently did the same. The results, shown here, are amazing. Carter chose a slightly redder shade of copper than Bakich, but that difference disappears when seen against a dark background.

I selected a slightly darker shade than Carter, but I was also looking away from the fireball when it appeared, concentrating on a much brighter part of the sky, so a successive contrast effect may have had a role in my observation. Still, when I compared all three observations against the same dark background, any color difference is slight. Was the copper color a true color shift?

According to the American Meteor Society, "The dominant composition of a meteoroid can play an important part in the observed colors of a fireball, with certain elements displaying signature colors when vaporized." Iron, one of the most common elements found in meteors, glows yellow to yellow brown, while sodium produces an orange-yellow hue, similar to the colors we observed.

A rip in heaven

One final note: Carter did see an additional afterimage effect. As the meteor moved across the sky, she saw it tear open a rift in the meteor's wake, as if allowing her to see the darkness of space beyond. The rift was the lingering dark-blue afterimage of the copper meteor streak, which remained visible briefly against the dawn's light as the fireball moved rapidly across the sky. As always, send your meteor observations and any thoughts to sjomeara31@gmail.com.

COSMIC WORLD

A look at the best and the worst that astronomy and space science have to offer. **by Eric Betz**

Cold as space — Supernova hot

Mars spectacular

On August 27, Mars appeared as big as the Full Moon in Earth's night sky for legions of gullible Facebook users led to believe they'd see two moons and likely still didn't bother to go outside.

Doomsday deniers

NASA says there's "not one shred of evidence" for any doomsday asteroids after an onslaught of blogs, spreading like an epidemic, announce Earth's demise in the middle of September. At press time, the world endured.

IAU who?

Tajikistan's president celebrates the "International Astrophysical Union" renaming an unspecified planet "between Mars and Jupiter" Tajikistan. In other news, I've renamed the Sun "Eric," and Earth now revolves around me.

Superhenge

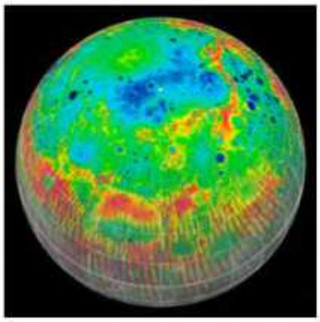
New radar maps of Stonehenge find 100 buried megalithic rocks possibly predating the well-known site just miles away. The study confirms prehistoric people knew more about astronomy than modern Facebook users.

(MARS SPECTACULAR) THIS ALTERED IMAGE WAS WIDELY SHARED ON SOCIAL MEDIA; (DOOMSDAY DENIERS) NASA/JHUAPL; (IAU WHO?) NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA; (SUPERHENGE) LBI ARCHPRO, JUAN TORREJÓN VALDELOMAR, JOACHIM BRANDTNER

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara.**

ASTRONEWS

SUPERSONIC STARS. Astronomers proposed studying the galactic center by looking for stars cruising through gas at supersonic speeds, thereby giving off shock waves detectable at radio wavelengths.



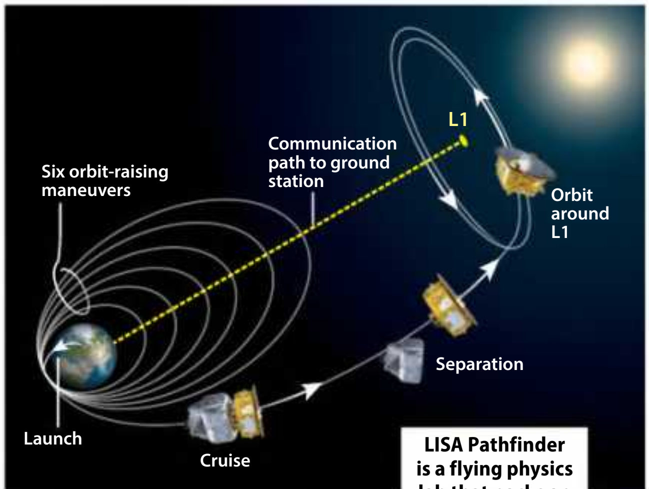
NASA/JHUAPL/CIW/DLR

ROUND AND ROUND. Researchers used MESSENGER's high-precision maps to ascertain Mercury's rate of rotation.

Mercury motion

Mercury's MESSENGER spacecraft crash-landed purposely to its death in April 2015, but scientists are still picking through its data for fresh insights. New research published October 3 in *Geophysical Research Letters* shows that Mercury spins on its axis about 9 seconds faster than scientists thought. Mercury is well known to turn three times on its axis for every two turns around the Sun, but it also exhibits smaller scale fluctuations in its rotational speed known as librations. The 3:2 orbital ratio made it clear that the Sun influenced Mercury's spin rate, but the new finding indicates that Jupiter may also be exerting its influence on the innermost planet. Mercury's next mission is the European Space Agency's BepiColombo set to launch in 2017. — **K. H.**

LISA TESTS GRAVITATIONAL WAVE TECH



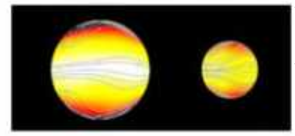
ASTRONOMY: ERIC BETZ AND ROEN KELLY; ESA-ATG MEDIALAB (SPACECRAFT)

FAST FACT

LISA Pathfinder is a flying physics lab that packs an optical laser bench with 22 mirrors and beam splitters.

RELATIVITY RIPPLES. LISA Pathfinder — the first space-based gravitational wave detector — was scheduled to launch December 2, 2015, but its origin goes back a century. In 1916, following his revolutionary General Relativity theory, Albert Einstein predicted that extreme objects could create gravitational waves. But no one's ever found them. The European Space Agency hopes to change that with LISA and allow astronomers to study the universe for the first time outside the electromagnetic spectrum — letting them "hear" the universe, as the mission managers put it. The proof-of-concept mission uses lasers to connect several spacecraft into a sensitive interferometer. One laser beam aims at two free-falling test masses, while the other reflects through the bench. The two beam lengths are then compared in search of tiny distance changes. If LISA works, it could be the first of a new class of spacecraft.

5,000 solar masses The size of a newly found and rare intermediate-mass black hole



LUDMILA CARONE (KU LEUVEN)

KEEPING COOL. Two of three general possibilities for exoplanets locked with one side always toward their sun may yet be habitable.

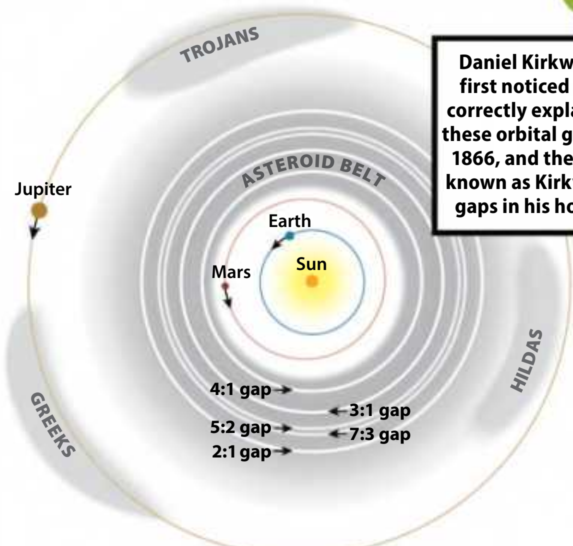
Exoplanet air conditioning

Many exoplanets live around tiny red dwarf stars. These stars' dimness means exoplanets must orbit close in order to absorb enough heat to be habitable — so close, in fact, that they likely will be tidally locked, with one side always facing their sun. Such an arrangement could lead to lopsided weather that rules out habitability anyway, with one hemisphere roasting while the other freezes. But scientists from KU Leuven in the Netherlands have developed 3-D models showing that two of three possible climates arising on such planets would be potentially habitable, with favorable wind jets distributing heat around the planet. Their research was published in the *Monthly Notices of the Royal Astronomical Society* on September 13. — **K. H.**

GROUPS AND GAPS

FAST FACT

Daniel Kirkwood first noticed and correctly explained these orbital gaps in 1866, and they are known as Kirkwood gaps in his honor.



MIND THE GAP. Asteroids in the main belt avoid "resonance orbits" with periods that form integer ratios with Jupiter's period, due to the king of planets' mighty gravitational sway. But other asteroid families cluster at Jupiter's orbit, leading and trailing their puppet master. *ASTRONOMY*: ROEN KELLY AND KOREY HAYNES

NASA/JPL-CALTECH/MSSS

Curiosity sees petrified sand dunes

Lake turned to dunes. Dunes became sandstone. That's the scientific consensus after NASA's Mars Science Laboratory Curiosity crawled past these petrified sand dunes, called the Stimson unit, in September, stopping to snap dozens of photos that were stitched into this panorama. Mission scientists say the crossbedding resembles features seen in the American Southwest. And by studying the crisscrossing patterns, it's possible to see which way the wind blew billions of years ago. As Curiosity climbs higher up Mount Sharp, the rover is stopping more often to drill such sites. — **E. B.**

OBSERVING**BASICS**

BY GLENN CHAPLE

New month, new target

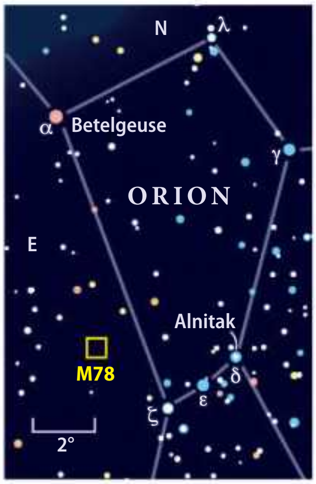
Kick off the New Year by joining the Las Vegas Astronomical Society's Observer's Challenge.

In my March 2015 column, "Astronomical game plans," I stressed the need for an organized observing program to lessen an individual's risk of astronomical ennui. The Astronomical League's observing programs, highlighted in the article, are a giant leap in that direction.

If you'd prefer a "small step" approach, I encourage you to look into the Las Vegas Astronomical Society's (LVAS) "observer's challenge." Each month, the editors of this program highlight a noteworthy object. They encourage people to make an in-depth observation and send a brief report that includes descriptive notes and a sketch or image. Shortly after month's end, they post the submissions on the LVAS website.

Also on the website is an archive of past observer's challenges, which resulted from an experience current LVAS Vice President Fred Rayworth had at a star party in late 2008. Rayworth notes: "While we had a variety of scopes on site, the chatter was almost exclusively about imaging. … Not a single person was talking about looking through an eyepiece!"

Rayworth's subsequent rant on the LVAS website elicited an email from North Carolinian Roger Ivester. Rayworth continues: "In Ivester, I had a long-lost visual kindred spirit on the other side of the country. After corresponding for a few months, he suggested we try to stir the pot and inspire others to take up, or at least participate in more,



Spend each month of 2016 targeting one object in-depth. M78 in Orion is a great place to start. *ASTRONOMY*: ROEN KELLY

visual observing. We created the observer's challenge."

With an assist from LVAS President Rob Lambert, the first observer's challenge (appropriately, the Crab Nebula [M1], the first object on Messier's list) appeared on the LVAS website in February 2009. As of this past December, the LVAS has spotlighted 125 challenge objects.

Despite the name, most featured objects in the challenge are well within the reach of ordinary scopes. Reports from individuals living in urban or suburban areas are welcome. One goal of the challenge is to assemble observations made with a variety of instruments under diverse conditions.

Ivester, Rayworth, and Lambert invite you to participate in the January 2016 observer's challenge by setting your sights on M78, Orion's "other" Messier nebula. Though greatly overshadowed by the Orion Nebula (M42), M78 has the distinction of being the brightest diffuse reflection nebula (one whose light comes from nearby or embedded stars) in the sky. M42 and similar bright luminaries like M17 and M20 are basically diffuse emission nebulae that give off their own light.

What will you see when you aim your telescope at the sweet spot 3° northeast of Alnitak (the Delta [δ] star in Orion's Belt) and peer into the eyepiece? I ain't gonna tell ya! You'll need to look for yourself. No quick glance either. Observe! Take notes that include date and time, sky conditions, equipment used, and a description of what you saw when you looked at M78. If you've seen M78 before, visit it again. Try binoculars or a different size scope. Experiment with nebula filters. Me? I'll view M78 from my backyard using my 2.4-inch refractor in an effort to determine the detail such a small instrument under my slightly light-polluted suburban skies can reveal.

Next, make a sketch — no "I'm not a good artist" excuses allowed! We're looking for a basic pencil-on-paper rendering of what you see at the eyepiece, *not* a Rembrandt masterpiece. If you need art lessons, visit *Astronomy*'s Astro Sketching column, hosted by our artist-in-residence Erika Rix.

When you're done, assemble your notes and sketch (or your image) and submit them. For more information on the LVAS observer's challenge and access to the archives, head to www.lvastronomy.com/observing-challenge.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: We get "Sirius." Clear skies!

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

FROM OUR INBOX

NASA funding or global warming?

I was disappointed to see a political article, "Intentional ignorance," (October 2015, p. 14) on global warming in *Astronomy*. The article, purportedly about funding decreases for NASA's Earth science program, becomes a polemic, blaming budget cuts on global warming "deniers." The article fails to identify the percentage represented by the "slashed" three-quarters of a billion dollars. In fact, NASA's 2015 budget of $18 billion will fund the Space Launch Systems, the Webb space telescope, and more. Perhaps global warming has run its course, and hard science is now a higher priority.

Can *Astronomy* get back to astronomy? I look forward to reading *Astronomy* as a welcome respite from political controversy. — **Joe Guilfoyle,** Virginia Beach, Virginia

Carbon dioxide controls the thermal balance between sunlight and reradiated infrared on each of the terrestrial planets. It's fun, straightforward science that makes Venus, Earth, and Mars what they are. It's just the kind of thing Astronomy *readers love!*

A simple consequence of that neat science is that radically increasing atmospheric carbon dioxide is a lot like wearing thermal underwear in Phoenix in August. Things are going to heat up. When did, "physics works on Earth, too" become a political statement?

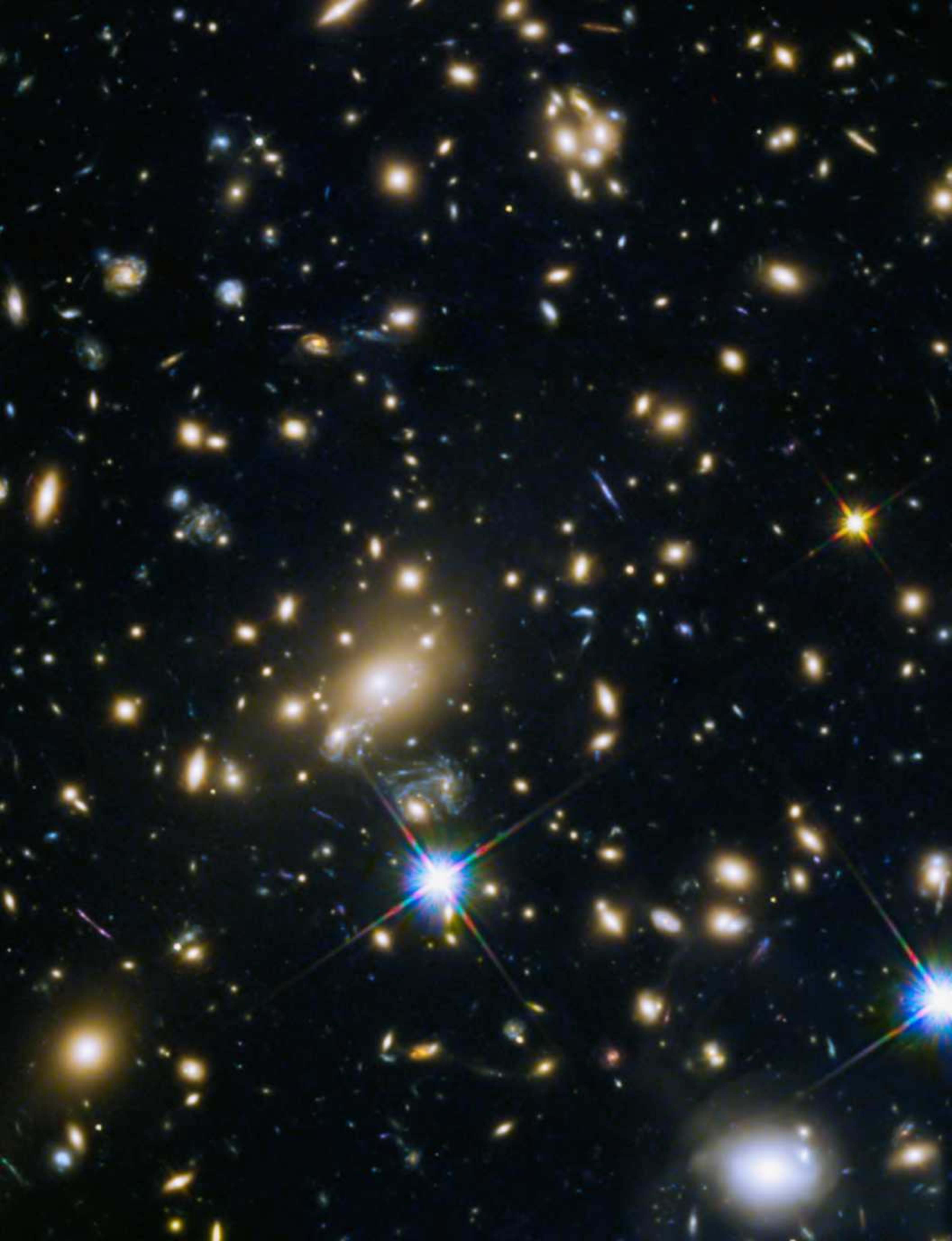
Science is not a respite. Science is a powerful tool for seeing the world as it is. The cuts, which ignore clear scientific agreement about NASA priorities, represent up to 38 percent of NASA's Earth science budget and accompany deep cuts to the National Oceanic and Atmospheric Administration. When politicians suppress science, then simply ignore the laws of physics, scientifically-minded people have a responsibility to speak up. Astronomy*'s readership is sophisticated enough to hear that.* — **Jeff Hester**

TOP 10 SPACE STORIES *of* 2015

Astronomers find signs of dark matter close to home, unravel the mystery of a famous supernova, and take a trip to Pluto.

by Liz Kruesi

Astronomy *Contributing Editor* **Liz Kruesi** *writes about the wonders of the cosmos from Austin, Texas.*



Planetary science drew the most attention in 2015, and for good reason. Mysterious bright spots on the largest asteroid in our solar system puzzled scientists. The spacecraft following a comet as it hurtled toward and then retreated from the Sun continued to make surprising discoveries. And, of course, the year saw the history-making and expectation-shattering observations of Pluto.

But discoveries about celestial objects beyond the solar system deserve attention, too. The center of the Milky Way Galaxy harbors a mysterious glow from dead stars or something even stranger, while astronomy's most studied stellar explosion is changing before our eyes.

Each year, *Astronomy* ranks the top 10 astronomical discoveries and space stories. Here's where 2015's biggest ones fall.

10 The Red Planet under water

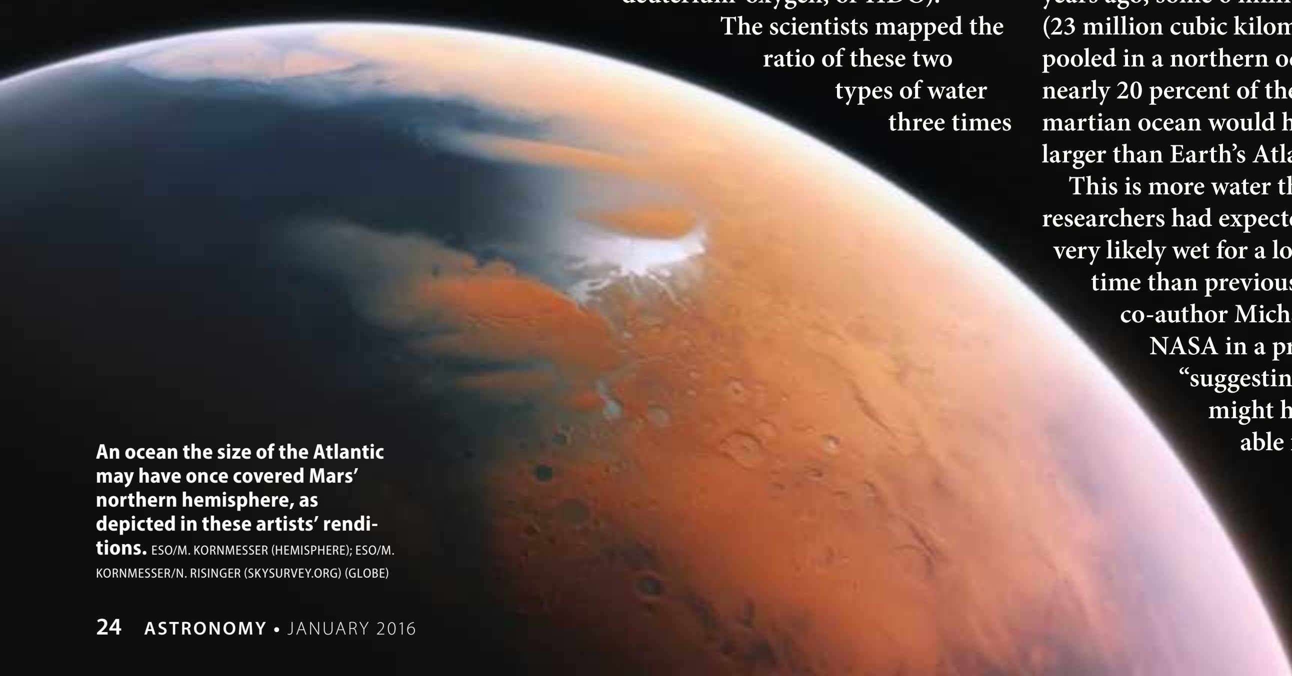
The rovers and orbiters at Mars have uncovered plenty of evidence that the planet once had liquid water on its surface, from etched river gullies and dried-up shorelines to minerals that need water to form. But a new study, some five years in the making, confirms that the Red Planet hosts liquid water on its surface today. Since 2010, Lujendra Ojha, from Georgia State University, and colleagues have used Mars Reconnaissance Orbiter (MRO) data to study streaks running down martian crater walls. They suspected that the streaks, called "recurring slope lineae," which appear to lengthen from one image to the next, mark flowing salt water. But they didn't have proof. In the new study, published in the September 28 issue of *Nature Geoscience*, Ojha's team provides the spectral signature (from MRO) of salty water at four locations of recurring slope lineae on the Red Planet's surface — confirming that flowing water is present today on Mars.

While little water remains today, scientists know that it must have been bountiful in the past. A study published in the April 10 issue of *Science* analyzed how much water the planet once had. Researchers used several Earth-based telescopes to look at the martian atmosphere in infrared light. Geronimo Villanueva of NASA's Goddard Space Flight Center and colleagues were looking for specific colors: one that corresponds to normal water (H_2O) and one that comes from a heavier form of water that has an extra neutron (hydrogen-deuterium-oxygen, or HDO).

The scientists mapped the ratio of these two types of water three times over six years (or three martian years) to compare the water in the atmosphere at different seasons.

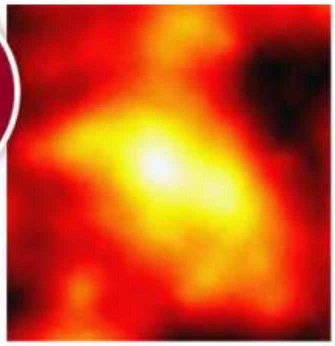
H_2O is lighter than HDO and thus evaporates more easily. So by measuring the ratio of the two, the researchers could calculate how much water Mars has lost over time, and thus how much water it would have started with. Villanueva's team says that 4.5 billion years ago, some 6 million cubic miles (23 million cubic kilometers) of water pooled in a northern ocean covering nearly 20 percent of the surface. This martian ocean would have been a bit larger than Earth's Atlantic Ocean.

This is more water than many researchers had expected. "[Mars] was very likely wet for a longer period of time than previously thought," said co-author Michael Mumma of NASA in a press statement, "suggesting the planet might have been habitable for longer."



An ocean the size of the Atlantic may have once covered Mars' northern hemisphere, as depicted in these artists' renditions. ESO/M. KORNMESSER (HEMISPHERE); ESO/M. KORNMESSER/N. RISINGER (SKYSURVEY.ORG) (GLOBE)

Dark matter hints next door



NASA/DOE/FERMI-LAT COLL./GERINGER-SAMETH/WALKER/CMU/KOUSHIAPPAS/BROWN UNIV.

Dark matter annihilation may be the cause of the gamma-ray glow emanating from nearby dwarf galaxy Reticulum II, shown here in red and yellow.

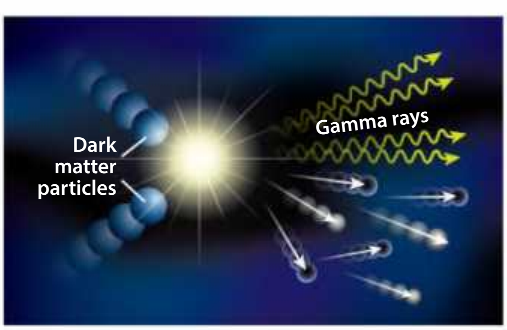
The invisible and perplexing material that makes up at least 80 percent of our universe's mass keeps leaving clues for astronomers, but not enough to solve its identity. While scientists do not know yet what makes up this dark matter, one search method has given tantalizing hints over this past year.

Scientists believe that when two dark matter particles collide they destroy themselves — a process called annihilation — and create other familiar particles. Among this shower of particles is gamma radiation. And nearby dwarf galaxies are an ideal place to look for dark-matter-produced gamma rays. "[Dwarf galaxies] are calm, quiet places; we don't know any reason why they should be emitting high-energy gamma rays on their own," says Carnegie Mellon University's Alex Geringer-Sameth, lead scientist of one of the searches. "Therefore, if you see some gamma rays coming from one of these dwarf galaxies, it is very exciting because it could be a sign that dark matter is annihilating within it."

This past year, a sky survey uncovered nine dwarf galaxies within 1 million light-years of the Milky Way. And one of the galaxies from this Dark Energy Survey (DES) was a prime dark matter target: Reticulum II.

Geringer-Sameth's team and another — Dan Hooper and Tim Linden, both of the University of Chicago — used seven years of data from the Fermi Gamma-ray Space Telescope to find that this dwarf galaxy looks a bit brighter than it should in gamma rays. "We provide an indication that *something* is emitting gamma rays from the direction of Reticulum II, and that something seems to be consistent with dark matter annihilation," says Geringer-Sameth. "While the signal from Reticulum II is tantalizing, it would be premature to conclude it has a dark matter origin."

Hooper and Linden calculated a similar chance that the signal has dark matter origins. "You might call that evidence; you won't call that a discovery," Hooper says of the studies. "We really need more data to resolve the issue." Scientists expect DES to uncover some 20 more nearby dwarf galaxies, and future surveys will find even more. Scientists will then be able to compare archived Fermi gamma-ray data with these dwarf galaxies to see if they have a signal similar to Reticulum II's.



When dark matter particles collide, they may annihilate each other in a shower of other particles, including gamma rays. *ASTRONOMY*: ROEN KELLY

Astronomers used the Hubble Space Telescope to catch a faraway galaxy focusing the light of an even more distant supernova four times over. NASA/ESA/STScI/UCLA

Supernova hunters see quadruple

In November 2014, Patrick Kelly was looking through his team's recently collected Hubble Space Telescope images of galaxy cluster MACS J1149.6+2223 when something stood out: four stars with exactly the same pattern of light surrounding one of the cluster's member galaxies. "I knew it was a big discovery," says Kelly, a postdoctoral fellow at the University of California, Berkeley. He emailed his group about the find, and they have since confirmed it as a supernova whose image has been distorted by the cluster galaxy, which lies along the supernova's line of sight. Months of observations have classified this object as a type IIp supernova, which originated from a massive star.

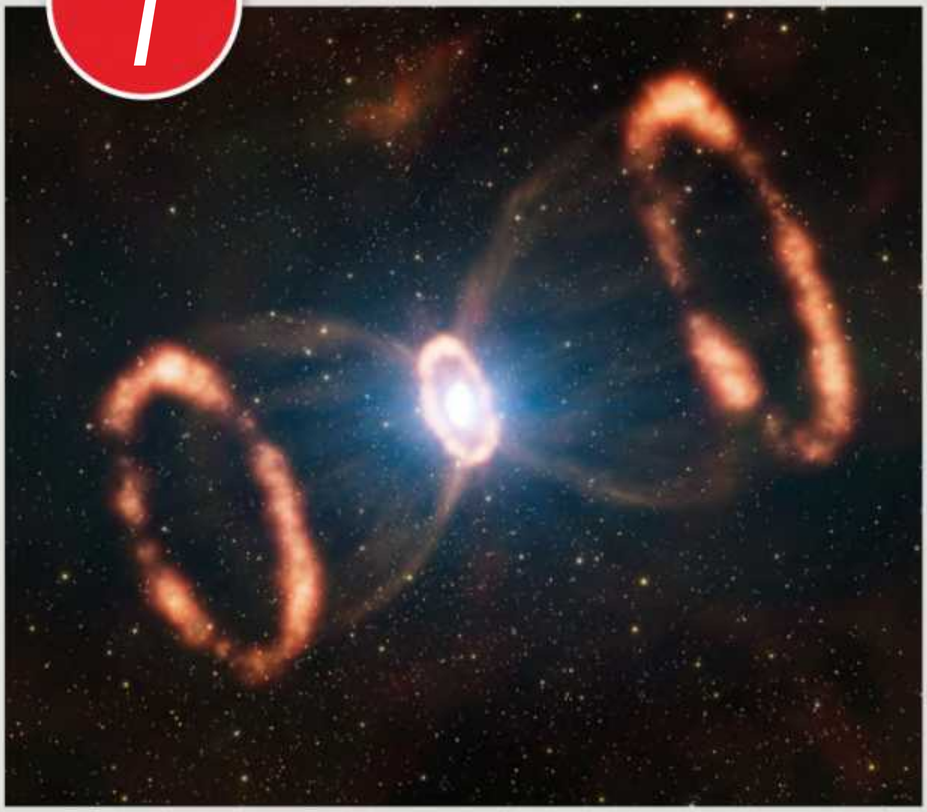
The distant stellar explosion lies more than halfway across the observable universe. Its light left the supernova some 9.5 billion years ago. Along its path to Earth, the light encountered a massive member of the intervening galaxy cluster. The galaxy warps the fabric of space-time like a bowling ball warps a trampoline, and so the supernova's light follows those curves in space-time, detoured from its path to Hubble.

This "gravitational lensing" causes the light to appear to come from four different points instead of just one lone supernova. Norwegian astrophysicist Sjur Refsdal predicted this type of quadruple-lensed supernova 50 years ago. The 2014 discovery, published in the March 6, 2015, issue of *Science*, has been named Supernova Refsdal after that scientist.

In his 1964 paper, Refsdal said such a blast could help to measure the rate our universe is expanding. Because the explosion's images show up in four locations, light followed four different paths to arrive at Hubble. Astronomers can use each of those paths to map the distribution of normal material and unseen dark matter in the galaxy cluster. In addition, those different paths are related to the cosmic expansion rate.

Another spectacle awaits the team. All of those paths also take a different travel time. After creating a map of MACS J1149.6+2223, the astronomers realized that the supernova should have taken a fifth path, too. The light is still traveling and could appear as early as late 2015, says Kelly.

7 Deciphering a famous supernova



An artist's work depicts Supernova 1987A observations that show the fading ring of debris. ESO/L. CALÇADA

In February 1987, a brilliant new point of light shone in the southern sky. This turned out to be the explosive blast marking the death of a star and earned the name Supernova 1987A. Lying just 168,000 light-years from Earth, it is the closest supernova to explode since astronomers developed the tools to study such a blast. And that proximity makes it a perfect laboratory to watch how supernovae evolve. Several discoveries published in 2015 reveal changes to the blast site and uncover secrets of the explosion first seen 28 years ago.

SN 1987A is recognized by its ring of bright nodules, like shining diamonds along a band. These brilliant spots mark where the blast's shock wave is slamming into previously shed material. While astronomers had seen the diamonds brightening for the past 15 years, new observations show them fading for the first time. This means the blast's shock wave is passing through the ring of material, breaking it apart. Visible-light observations made by Stockholm University's Claes Fransson and colleagues using the Hubble Space Telescope show the ring is fading, while spots outside of the ring are beginning to light up. They described the observations in the June 10 issue of *The Astrophysical Journal Letters*.

X-ray images from the Chandra X-ray Observatory also show the ring's light changing. David Burrows, who has been watching SN 1987A evolve for 15 years, says the blast's high-energy light is plateauing.

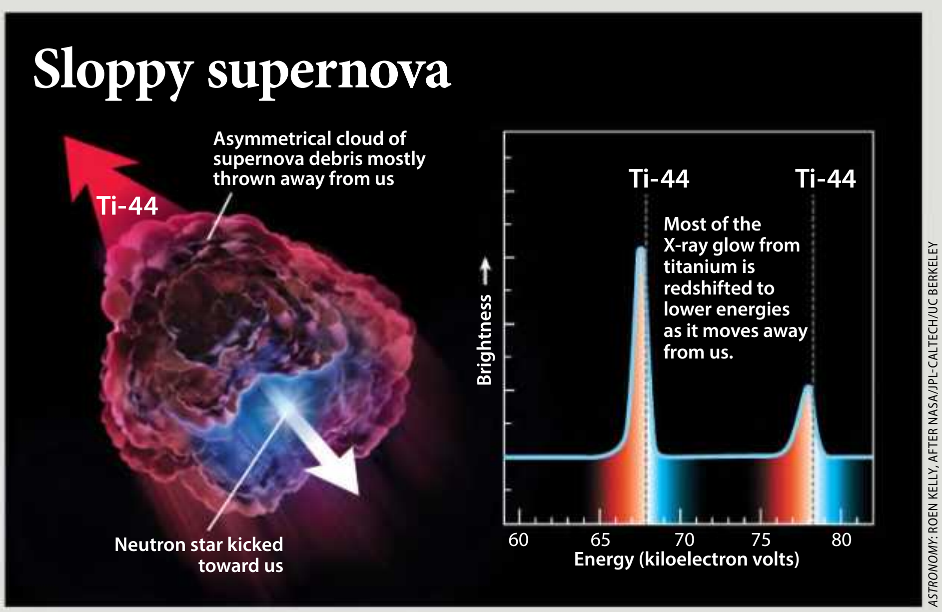
Another 2015 study focused on SN 1987A's guts.

When a star at least 10 times the Sun's mass explodes at the end of its life, the energies, temperatures, and pressures are so high that the supernova produces a range of heavy chemical elements. One of those is titanium-44 (Ti-44), which is an unstable radioactive isotope. "The isotope is produced deep in the core of the explosion, and its properties — mass, ejection speeds, and distribution — directly reflect the physics in the core," says Steve Boggs of the University of California, Berkeley.

Like all elements, Ti-44 glows with specific colors of light, so if scientists look for those colors, they can learn where that material is. But none of Ti-44's colors had been visible to astronomers until a recent X-ray telescope, the Nuclear Spectroscopic Telescope Array (NuSTAR), opened its eyes and began collecting data.

Boggs and colleagues described in the May 8 issue of *Science* their study using NuSTAR to map Ti-44 in SN 1987A. The element's distribution is clumpy and uneven, implying that the explosion was off-center. This is the second supernova remnant the team has been able to probe; the other is Cassiopeia A. Both explosions were asymmetrical, Boggs' team says, which means now astronomers have to rethink the theoretical models of these blasts.

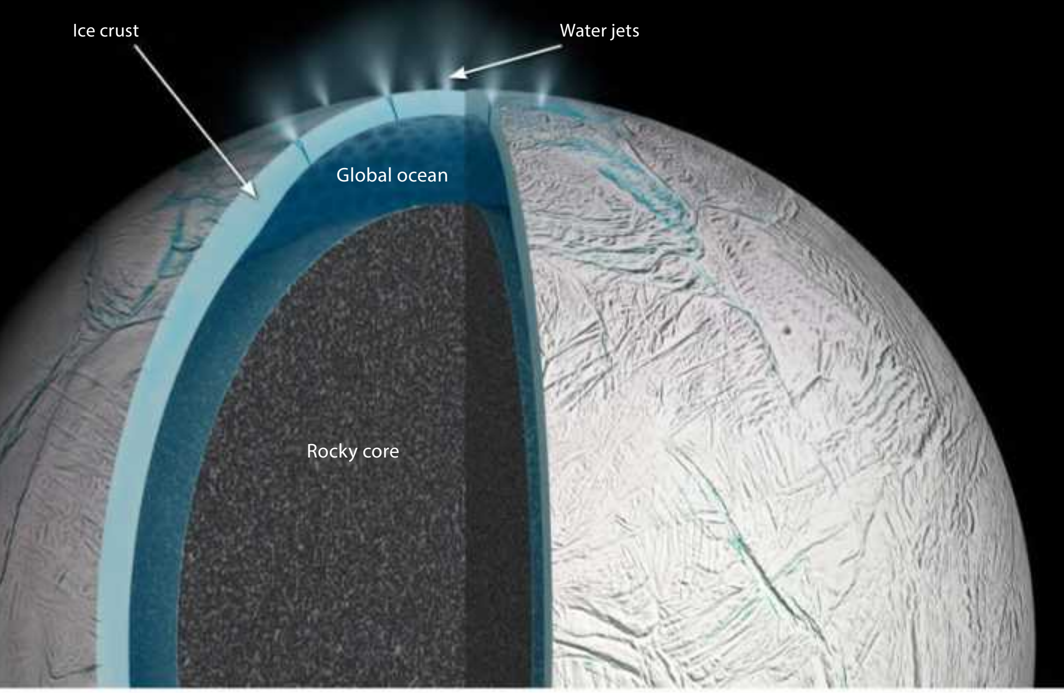
Most computer models have assumed a symmetrical blast, but the new studies prove something more complex is happening.



X-ray observations mapping titanium-44 created during Supernova 1987A show that the explosion was a lopsided event, with the bulk of material streaming away from Earth.

6

Water abounds in the outer solar system



Saturn's moon Enceladus is spewing out rocky silicate grains that researchers found form in hot acidic water — the same kind of hydrothermal vents where deep-sea life thrives on Earth. NASA/JPL-CALTECH

Saturn's moon Enceladus continues to show why it's one of the best bets in the solar system to search for life. Astronomers have suspected for years that salty water dredged up from a subsurface sea spews into space out of fissures near the moon's south pole. But an analysis, published online September 11 in the journal *Icarus*, of seven years of images from NASA's Cassini spacecraft indicates that Enceladus has a subsurface global ocean instead of merely a regional sea.

Cornell University planetary scientist Peter Thomas and colleagues measured a slight wobble in the moon's rotation. If Enceladus were solid, its mass would dampen that motion. The researchers believe, instead, that a liquid water ocean lies between the moon's icy surface layer and the rocky interior. They say the ocean is deeper and the ice shell thinner at the south polar region, where Cassini has spied some 100 geysers of salt water.

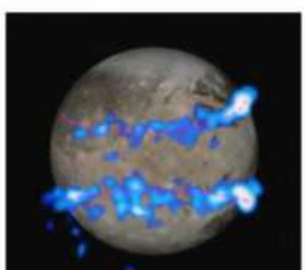
Scientists think that to keep any material in liquid state within Enceladus' interior requires the push-and-pull tidal energy from Saturn. A global ocean is harder to keep warm than a regional sea, and so this discovery could also indicate that the saturnian satellite has more tidal energy than originally thought. "If that is correct," says team member Carolyn Porco, "and its ocean has been around a long, long time, then it may mean that any life within it has had a long time to evolve."

Some of the material spewing from Enceladus' underground ocean flows out through the geysers, flows toward Saturn because of the planet's gravitational pull, and then orbits the planet as its E ring. In the March 12 issue of *Nature*, Frank Postberg at the universities of Heidelberg and Stuttgart in Germany and colleagues described how they used the Cassini spacecraft to study some of the material from the E ring. They saw silicon-rich molecules (called silicates) just a few nanometers wide. When this type of material is found in space, it almost always originates from rock being dissolved in water. But to learn the precise characteristics of that water-rock interaction, Postberg's team collaborated with researchers from Japan to mimic the conditions needed at Enceladus to produce the sizes and composition of silicate particles they observed. They found the water needs to be at least 194° F (90° C) and have a pH between 8.5 and 10.5. These characteristics imply hot-spring-heated water; the only other place where such hydrothermal vents have ever been seen is on Earth, and these sites host extreme organisms.

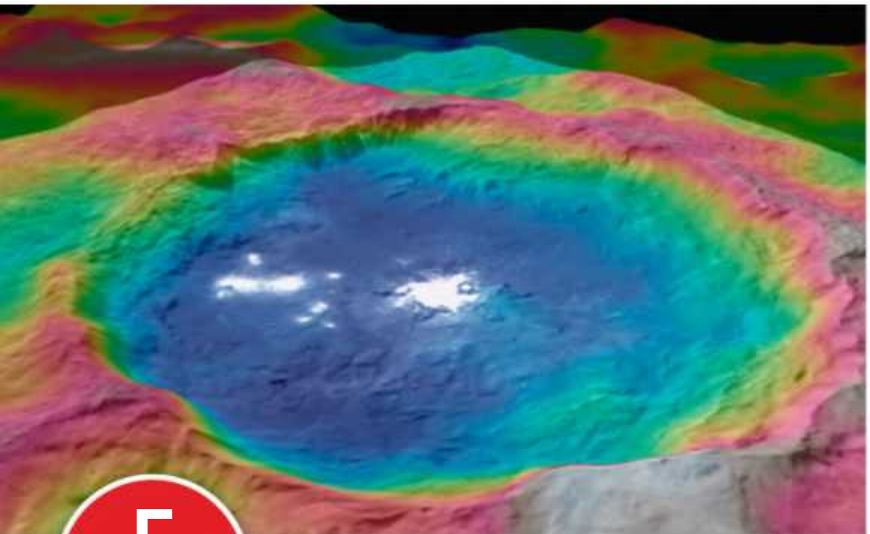
The chemical reaction that produces the silicates also creates molecular hydrogen, and a different instrument on board Cassini will look for this gas during a late 2015 flight through Enceladus' plumes. If it detects more molecular hydrogen than expected, it will confirm hydrothermal activity, says Postberg.

This year, astronomers also found the best evidence so far of water at yet another location in our solar system: Jupiter's large moon Ganymede. NASA's Galileo spacecraft, which studied the jovian system in the late 1990s and early 2000s, studied Ganymede's magnetic field to learn whether the moon holds a global ocean under its surface. But the analysis from only 20 minutes of flyby observations was inconclusive. Fast forward to the past year, when Joachim Saur of the University of Cologne and his colleagues studied data from two 7-hour Hubble Space Telescope observations.

Ganymede has an auroral belt in each hemisphere just like Earth does. Jupiter's magnetic field also influences these aurorae and causes them to rock during Jupiter's 10-hour rotation period. Saur's team knew that if Ganymede did not have an ocean, the aurora belts would change their positions slightly, tilting about 6°. "However, when a salty and thus electrically conductive ocean is present, this ocean counterbalances Jupiter's magnetic influence and thus reduces the rocking of the auroras to only 2°," says Saur. "We observed Ganymede with the Hubble Space Telescope for more than five hours and saw that the aurora barely moved and rocked by only 2°. This thus confirms the existence of an ocean." The researchers think the ocean lies about 90 miles (150km) below the moon's rock-ice crust and is about 60 miles (100km) thick. This strong evidence of Ganymede's ocean continues to increase the number of worlds in our solar system known to host water.



Jupiter should exert a strong influence on its moon Ganymede's magnetic field, causing its aurorae to rock. But astronomers see only a tiny effect, implying that an underground saltwater ocean is offsetting Jupiter's influence. NASA/ESA



5

Ceres is color-coded here to highlight the topography of Occator Crater with its bright spots. Low elevation is shown in blue and green and high regions in red and brown. NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

Ceres takes center stage

Since March 6, NASA's Dawn spacecraft has been in orbit around Ceres, the largest object in the asteroid belt lying between Mars and Jupiter. For a full recap of the spacecraft's adventures and discoveries, see "Dawn mission reveals dwarf planet Ceres" (p. 44). Dawn will continue its studies until June 2016. Ceres is the second asteroid Dawn has orbited; the first was Vesta, between July 2011 and September 2012.

Ceres' pockmarked surface is riddled with craters like those seen at Saturn's icy moons. "The features are pretty consistent with an ice-rich crust," said Dawn planetary geologist Paul Schenk of the Lunar and Planetary Institute in Houston in a press statement. The spacecraft has mapped the heights of surface features like craters and mountains.

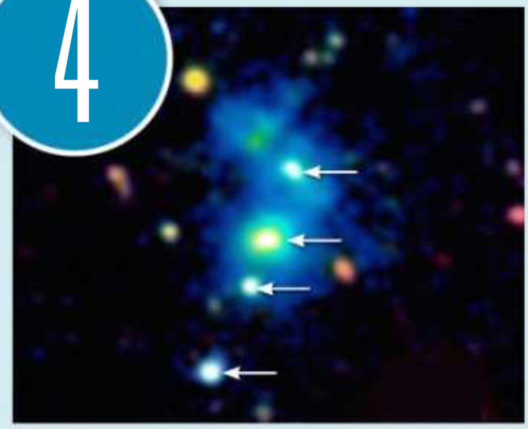
Bright spots on the dwarf planet's surface also have mystified planetary scientists. These reflective regions first came into view at the beginning of 2015 and have since resolved into a multitude of spots. They sit within Ceres' northern Occator Crater, which spans 57 miles (92km) and is 2.5 miles (4km) deep. Researchers at first believed they were ices or salts, but bad luck repeatedly stymied their efforts to gain spectra of the mysterious spots. Based on the reduced reflectivity of the spots, however, the consensus is turning to salt.

In August, Dawn had reached its penultimate orbit, circling Ceres from 910 miles (1,470km) out. A few months later, the spacecraft will have transitioned to its final science orbit, at just 230 miles (375km) above the surface.

In addition to mapping the surface and measuring the heights of the mountains and craters on Ceres, Dawn is working to learn about the composition of materials on the asteroid's surface. The spacecraft also is measuring how different locations on Ceres pull with more or less gravity. The answers will let scientists map the world's gravity and learn how the dwarf planet's rocky interior is distributed.

NASA's Dawn mission has spotted these bright features on Ceres, which are likely salt deposits. NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

4



HENNAWI AND ARRIGONI-BATTAIA (MPIA)

These four quasars, the bright centers of active galaxies, are all the same huge distance from Earth. Their proximity to one another makes them the earliest galaxy cluster yet.

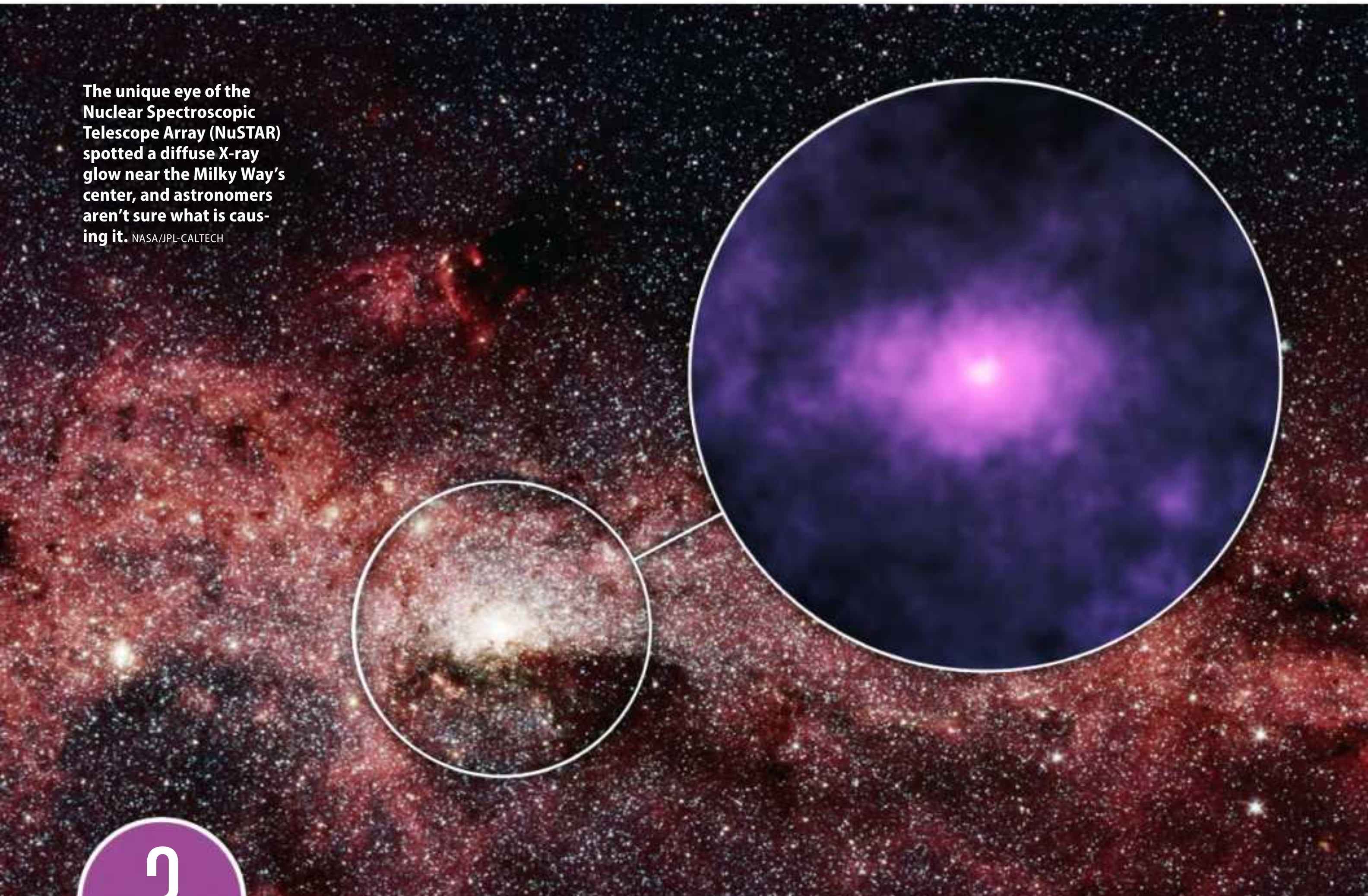
Youngest cluster of galaxies seen

The process of forming clusters of galaxies is not one that astronomers can watch in real time because it takes billions of years. Instead, they look for galaxy clusters at different stages in their development. Because light travels at a constant speed, the light collected from more distant objects means scientists are seeing those objects further back in time. In 2015, astronomers reported they had found the youngest cluster yet, still in an early stage of formation.

To find this protocluster, Joseph F. Hennawi of the Max Planck Institute for Astronomy in Heidelberg and colleagues searched for the extremely bright centers of galaxies hosting actively feeding supermassive black holes. These quasars, as they are known, are used in two ways: first, as markers for large galaxies, and second, as flashlights to see through nearby gas clouds. Such gas clouds glow because they absorb the active galaxy's light and then re-emit it. The researchers were looking for a specific color of light that energized hydrogen throws out, called Lyman alpha.

They spied four active galaxies near to one another on the sky. When they studied their light in more detail, they saw all four lie the same distance from Earth and the light from these objects has been traveling for 10.6 billion years. No one had ever seen, nor expected to find, four quasars in the same gravitationally bound group, so this discovery was a surprise.

The team also saw these galaxies embedded in an enormous cloud of hydrogen. The conglomeration existed when the universe was just about 3.2 billion years old, and the gas clump stretches about 1 million light-years across. "It's 100 percent clear that it's a protocluster," says team member J. Xavier Prochaska of the University of California, Santa Cruz. "It's a structure that will evolve into something like [the] Virgo [Cluster] today."



The unique eye of the Nuclear Spectroscopic Telescope Array (NuSTAR) spotted a diffuse X-ray glow near the Milky Way's center, and astronomers aren't sure what is causing it. NASA/JPL-CALTECH

3 A surprise glow at the galaxy's center

When astronomers have a new telescope that can resolve types of light never seen before, they can usually expect a surprise. And that's exactly what the Nuclear Spectroscopic Telescope Array (NuSTAR) uncovered when it collected a million seconds worth of high-energy X-ray light from the center of the Milky Way. Astronomers found a diffuse glow, but they can't pin down what's causing it.

Kerstin Perez was using NuSTAR data to study the glowing material around a neutron star lying in the galactic center. But she couldn't get rid of a pervasive signal in the central 13 light-years by 26 light-years. Once she convinced herself and her colleagues that this signal truly exists, they went to work to figure out what it could be.

NuSTAR doesn't just take pictures; it also spreads the light out in a spectrum, collecting information about the intensity of light at each individual color to make it easier to analyze. To figure out what creates the haze the researchers saw, they considered types of objects that would give a similar light pattern, says Perez. "And then you think, how many of those objects would you have to have in order to make up how bright we see it." This analysis led the NuSTAR team to four possibilities, which they described in an April 30 *Nature* article.

Three of the possibilities are stellar remnants stealing gas from a companion. As this material piles up, it ignites and glows in X-rays. The idea is that there are so many of these pairs that NuSTAR can't separate them from one another, so they appear as a haze.

One of these types of corpses could be thousands of white dwarf stars, each 90 percent of the Sun's mass. Another could be about a thousand black holes and neutron stars — the dense leftover cores of once massive stars. And the third option is some thousand millisecond pulsars, which are neutron stars that have had so much material dumped onto them by their companions that their rotation rates have sped up dramatically. The problem is that astronomers have no idea how so many of these objects — whatever they might be — could exist in a small region in the galactic center.

The fourth possibility is that as material falls toward the supermassive black hole at the center of the Milky Way, some of it gets shot out at high speed. This streaming material could be interacting with nearby clouds of gas, causing them to glow. But the hazy glow that NuSTAR sees doesn't look oriented in the right way for this explanation.

While scientists with NuSTAR hope that upcoming telescopic observations can help narrow down which of these possibilities is responsible for this emission, they don't expect to learn the answer soon.

ESA/ROSETTA

ESA/ATG MEDIALAB

The European Space Agency's Philae lander (above) bounced several times before landing on Comet 67P/Churyumov-Gerasimenko (left) in November 2014, and then fell into deep hibernation. In 2015, it woke up again, but its final fate remains unknown.

2 Europe's visit to a comet

The European Space Agency's Rosetta spacecraft has been watching how Comet 67P/Churyumov-Gerasimenko changes as it passes through its closest approach to the Sun and then hurtles away. The history-making mission has revealed many cometary secrets.

Ever since Rosetta beamed back its first images of Comet 67P, scientists have wondered what made its unexpected double-lobed "rubber duck" shape. Now, they have an answer. According to a paper published October 15 in *Nature*, two separate objects collided to form the comet. To reach this conclusion, the researchers measured how regions were sloped, looked at the orientations of features on the surface, and calculated the local gravity across the surface.

Rosetta also has returned thousands of images of Comet 67P. It has photographed boulders balancing on just a small part of their surfaces, piles of rubble that seem to have come from falling rocks, and jets of gas spewing from pits dozens of feet across possibly created by sinkholes. The spacecraft also has spied about 120 bright areas several feet wide on the comet's surface, and scientists say these are most likely patches of water ice reflecting sunlight.

After analyzing data of one water-ice patch on the comet's "neck," scientists say the area seems to appear and disappear with the comet's 12-hour rotation. They think that as the region feels direct sunlight, ice on the surface and just an inch (a few centimeters) below are heated and turn directly to gas — a process called sublimation. The sunlight also warms the layers of ground beneath the region, and so further-buried ice makes its way as gas to the surface. As the patch rotates into darkness, the surface cools again and the just-risen gas turns to ice. The scientists, who reported this water cycle in the September 24 issue of *Nature*, say the process repeats each cometary day.

Rosetta's refrigerator-sized Philae lander had also studied the comet's surface, even though the sequence of events to land this spacecraft didn't go as planned. After dropping from Rosetta on November 12, 2014, and bouncing several times before finally tumbling to rest, Philae stayed alert for just around 60 hours before falling into hibernation. Because of its unplanned bounces, the lander was able to compare two different sites on the comet's surface. The first landing site appears to have a soft dusty material about 8 inches (20cm) thick covering a much harder material, possibly icy or crystalline in nature. Philae's final resting spot, however, lacks that dusty coating.

At the first landing location, the craft "smelled" 16 organic compounds, including four never before detected on a comet. Another instrument detected several gases at the same location, like water vapor, carbon monoxide, and formaldehyde. Comets are expected to be pristine relics from the early solar system, but Comet 67P has more complex chemistry than expected, and some of the molecules discovered on the comet's surface are important for biology.

After hibernating for seven months, Philae surprised everyone when it woke up again June 13. Over the next few weeks, Philae and Earth had spotty conversations, with the last command sent and received July 9. Scientists have no way to know whether Philae still sits atop Comet 67P, or whether it has been pushed off by actively spewing jets of gas.

Rosetta will continue watching Comet 67P through September 2016, at which point mission scientists will most likely try to land the spacecraft on the comet for a last look.

STORIES TO WATCH FOR IN 2016

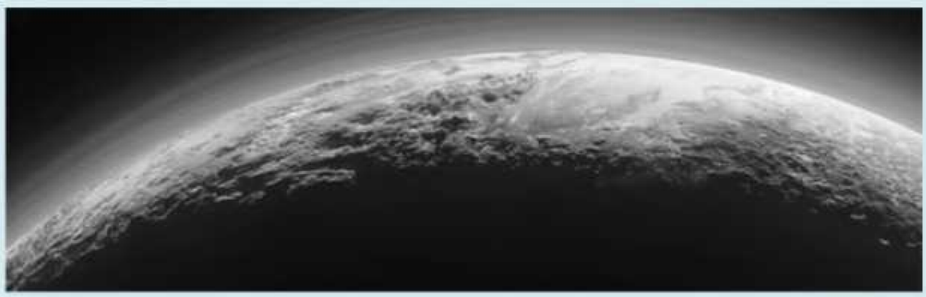
- The European Space Agency's LISA Pathfinder, a mission to test the technologies needed for a full-scale gravitational wave observatory, will begin to return results.
- The Japan Aerospace Exploration Agency will launch Astro-H to study the high-energy universe.
- NASA will launch its Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-Rex) asteroid sample-return mission.
- Astronomers will begin closing other telescopes on Hawaii's Mauna Kea in order to make way for the Thirty Meter Telescope slated to begin operations there in the early 2020s.
- Juno will arrive at Jupiter to peer through the giant world's thick clouds.
- Advanced Laser Interferometer Gravitational-wave Observatory (LIGO) will return data on gravitational waves.

CHECK OUT 2015'S OTHER TOP NEWS STORIES AT **www.Astronomy.com/toc.**

1 Pluto and its moons revealed

◄ **2015 was the "Year of Pluto," revealing the icy world and its moons in stunning detail and upending much of what we thought we knew about this system.** NASA/JHUAPL/SwRI

► **Pluto's largest moon Charon also came into sharper view, including glimpses of the dark region near its north pole informally known as Mordor Macula.** NASA/JHUAPL/SwRI



Pluto's distinct haze layers are clearly visible in this image returned by New Horizons. The extent of the hazes was a surprise to astronomers expecting a more elusive atmosphere. NASA/JHUAPL/SwRI

When NASA's New Horizons spacecraft flew by Pluto, Earth watched and celebrated. "The target didn't disappoint," says Principal Investigator S. Alan Stern. "It's absolutely stunning." And even though the science collection lasted just months, the New Horizons mission had been decades in the making. NASA chose the mission in 2001, the spacecraft launched in 2006, and it reached Pluto on July 14, 2015.

Seeing the pixelated blobs of Pluto and its largest moon, Charon, evolve into complex worlds through the eye of New Horizons was rewarding, satisfying, and awesome, says Stern. That's because everything about Pluto surprised scientists. They expected a frozen, cratered, and long-dead world with an equally old-looking system of moons. Instead, Pluto's surface is young, with smooth frozen plains, icy mountains as high as the U.S. Rockies, topography that resemble dunes, a glacial lake, and ice that has recently flowed around other features in the same way that glaciers move on Earth's surface. The scientists estimate that the uncratered swaths of terrain are 100 million years old, while other regions are billions of years in age.

Pluto's varied surface with such youthful areas means that something internal must be warming it to make it pliable. And while all the objects in our planetary system would have been warm shortly after the solar system formed 4.5 billion years ago, scientists didn't think such a small object could stay warm all these years. "We expect small planets to typically run out of energy a lot sooner than the big planets. It's like a small cup of coffee cools off faster than a bucket of coffee," says Stern. But what New Horizons has revealed about Pluto, he adds, changes the expectations of planetary geology.

Scientists have also created a map of methane ice distribution, and this material seems to prefer a region of young terrain that scientists have informally named "Sputnik Planum." Outside of this area, methane is still present and congregates on crater rims and brighter regions but avoids crater centers and darker regions for unknown reasons.

The up-close photos of Pluto have also let scientists precisely measure the width of the dwarf planet: 1,473 miles (2,370km). This secures Pluto as the largest known object orbiting beyond Neptune.

After New Horizons flew by Pluto, it looked back and watched the dwarf planet eclipse the Sun. This alignment let scientists study Pluto's atmosphere as sunlight filtered through it. Above the surface lie distinct haze layers that extend to about 80 miles (130km) out, several times farther than researchers expected. And New Horizons detected wisps of a nitrogen-rich atmosphere 1,000 miles (1,600km) out.

While Pluto has been the main focus, Charon also has shown surprises. It too has a varied surface, with some regions void of impact craters. Cliffs stretch hundreds of miles across the surface, indicating the crust has fractured. A deep canyon, 4 to 6 miles (6 to 10 km) deep, also scours Charon's surface.

New Horizons snapped photos of Pluto's four smaller moons as well: Nix, Hydra, Styx, and Kerberos. While Charon is 751 miles (1,208 km) across, each of these four is just a few dozen miles wide.

Most of New Horizons' data is still on board the spacecraft and will be downloaded piece by piece over the next several months. Researchers will pore over the additional data in the next few years, learning more every day about Pluto and its moons. Even though humans saved this dwarf system for last in our exploration of the solar system, just the first views exceeded and upended expectations and have given researchers a treasure-trove of new science.


Tom Benedict


Mary Beth Laychak


Daniel Devost

Is a cosmic career for you?

If your heart's set on an astronomy-related job, spend some time listening to the experts. **by Stephen G. Cullen**


Steve Bauman


Paul Gardner


Dan Birchall


Scott Kardel


Rick Hedrick

A wise man once said, "Choose a job you love, and you will never have to work a day in your life." That quote was never more true than it is with a career in astronomy. You might think a career in this science means enduring relatively low wages, odd working hours, and limited opportunities for advancement, but the outlook is much better than that. What is true is that there are relatively few open positions in professional astronomy, but with the current crop of really large telescopes both in planning and under construction, that's going to get better.

Now let's talk about the really great stuff — the cutting-edge jobs, unique co-workers, and amazing places you can call home. Even better, instead of just giving you my thoughts, I'm going to share some of the common themes I uncovered in talking with folks from some of the leading observatories, telescope makers, and retailers. I chose not to interview researchers for this story because I wanted to talk to the people at the heart of an observatory — the telescope operators, engineers, public information and outreach professionals, and administrators.

It's no secret that the research professionals get all the glory, yet the majority of the roles at observatories are behind the scenes. To help put that thought into perspective, consider this: Out of 44 positions at the Canada-France-Hawaii Telescope (CFHT), only 13 are research; at the Subaru Telescope, there are 138 jobs, yet just 35 of the staff have a research title; and, at the Gemini Observatory, a scant 31 out of 197 employees are researchers.

Keep in mind that there are many opportunities in astronomy besides a professional observatory — planetaria, science centers, equipment manufacturers, and retailers. I talked to owners and employees from those walks of life, too.

When did you get the astronomy itch? Many of the interviewees became interested in astronomy in their childhoods, typically before they were 10 years old. It should be no surprise that the NASA missions of the late 1960s and early 1970s — especially those with astronauts on the Moon — influenced many of them.

For Mary Beth Laychak, outreach program manager at the CFHT, a passing comet piqued her interest: "Growing up, I regularly watched *Star Trek*, and I loved the idea of exploring space. My dad is a retired high school physics and astronomy teacher, so I was lucky that he could answer most of my questions.

"His high school had a small telescope, and my sister and I would sometimes go with him during evening viewing sessions with his students. We saw Comet Hale-Bopp through the telescope, and I thought it was the most amazing thing."

How supportive were your family and friends? It seems to take a village to raise an astronomer. Besides developing a passion for the stars, nearly everyone remarked that they found ready support from parents, siblings, friends, and teachers.

Paul Gardner, former chief engineer at Palomar Mountain Observatory and now with the Giant Magellan Telescope, said: "Everyone in my life supported my hobby. Astronomy was something that I picked up on my own. My dad passed on a lot of great hobbies to me, but astronomy was not something he had an interest in. That said, my parents brought me to astronomy club meetings and let me stay out late on school nights so I could learn the sky."

What do you like best — and least — about your work? One of the interviewees said this about their job: "We have a running joke at work — every day is arts and crafts day at CFHT!" Others echoed similar sentiments; that is, you never experience the same day twice working at an observatory.

As for the downsides, people mentioned the long hours, working in the cold, and the drive to the "office." Observatories typically stand at high elevations at the ends of winding roads. It might not be as painful as the rush-hour commute in Los Angeles, but it could get old and dangerous, especially on moonless nights. Other negatives were meetings and administrative duties. Regardless of these challenges, 100 percent of those interviewed feel like they are living their dream job today.

What would you change about your career path? Nearly everyone thought that the time to change things was prior to entering the workforce. Individuals regretted not taking more varied studies, not diving in deeper, and not thinking more broadly about their interests while in college.

Steve Bauman, operations manager for the CFHT, captured the thought succinctly when he said, "I wish I would have had the opportunity to obtain an optical and electrical engineering degree as well as a mechanical degree so I would understand every aspect of the telescope and observatory design."

For now, however, everyone I talked to is enthused and committed to helping in some aspect of astronomy. Their message is clear: We did it. So can you!

Stephen G. Cullen *is co-owner of Starscape Gallery at Queens' Market Place at the Waikoloa Beach Resort on the Big Island of Hawaii.*

WHAT ADVICE WOULD YOU HAVE FOR A YOUNG PERSON INTERESTED IN A CAREER IN ASTRONOMY?

"I would recommend that everyone works hard to follow their dreams. Yes, there are far more people interested in astronomy than there are jobs in astronomy, but I still recommend pursuing that passion. It may or may not end up as a career for you, but if that is where your heart lies, it is important to follow that path to see where it leads." — **Scott Kardel**, professor of astronomy and assistant planetarium director, Palomar College

"My best advice to kids who want to become astronomers is to stay in school. A Ph.D. in astronomy takes about three to six years of graduate college studies after receiving a bachelor's degree. Students need to have an advanced knowledge of physics and mathematics and also have to learn how to write papers and reports. Also, good knowledge of electronic detectors that are used to take pictures is a plus for an astronomer but not necessarily required. This seems like a lot, but believe me, it is worth it!" — **Daniel Devost**, director of science operations, CFHT

"A 'career in astronomy' and a 'career as an astronomer' are not the same thing. If you want to become a research astronomer, get a doctorate from the best school you can get into, work hard, and hope for the best. But remember that roughly 90 percent of the people working in the astronomy community are not astronomers. We are operators, technicians, programmers, machinists, engineers, librarians, outreach professionals, and so on. And, in the future, we'll need more of all of those." — **Dan Birchall**, telescope operator, Subaru Telescope

"This is a wonderful time to be involved in astronomy. Our knowledge is changing so quickly, making it difficult to keep up. I used to think Edwin Hubble's time was the time to be in astronomy, but no, today is!" — **Rick Hedrick**, CEO and founder, PlaneWave Instruments

"Pursue your dreams, and ignore the naysayers. Learn as much as you can from each of your teachers. And never think it's too late. It's not." — **Tom Benedict,** instrument specialist, CFHT

ROTATIONAL RIDDLES

Q: I PREVIOUSLY UNDERSTOOD THAT MAGNETIC FIELDS WERE DIRECTLY RELATED TO ROTATION, SO WHEN I READ THAT MARS, LIKE VENUS, DIDN'T HAVE ONE, MY UNDERSTANDING CRUMBLED. WHAT EXACTLY CAUSES MAGNETIC FIELDS IN PLANETS?

***Kerry Dougan,** Jarabacoa, Dominican Republic*

A: Planetary magnetic fields are definitely related to rotation, but "directly" — not so much. They are actually generated by the complex interaction of fluid currents (motion of material) and electric currents (motion of electrons) in the conducting fluid of the molten metal core. This is called a "dynamo," and core convection is its primary driver, powered by cooling and crystallization growth of the solid inner core.

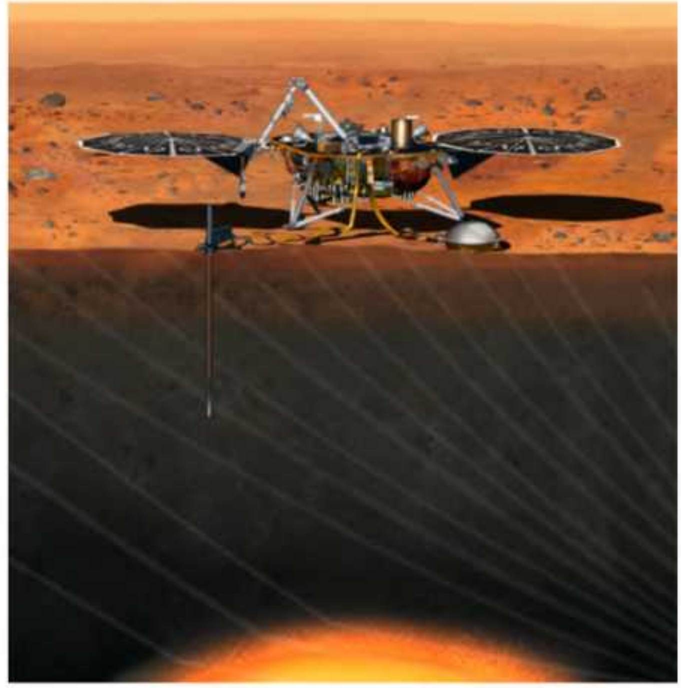
The importance of rotation is that it organizes the convective motion into cylindrical eddies aligned with the rotational pole. Thus, the fields generated by the rotation of these eddies throughout the core tend to line up in the same direction, adding together to form a strong dipole field. Without rotation, the convection would produce random eddies whose individual fields would be small and tend to cancel each other out.

This explains why the slow rotation of Venus would preclude a magnetic field. But what about Mars, which rotates nearly as fast as Earth and is known to have an iron core? First, the core may have cooled enough to have completely solidified; a spinning ball of solid iron doesn't produce a magnetic field.

However, there is other evidence that Mars' core is at least partly liquid. The more likely explanation is that convection in the liquid core has slowed to the point that it can't sustain a dynamo. This might be due to the core's heat being efficiently removed through the mantle early in Mars' history, resulting in a relatively cool core that still may be hot enough to be molten.

Or, paradoxically, it may be due to inefficient heat loss from the mantle. This would cause the mantle to stay hot, which would increase the temperature at the top of the core. Since thermal convection is driven by the difference in temperature between the top and bottom of the fluid, this would be equally effective in stopping convection, and thus shutting down the magnetic field-producing dynamo.

W. Bruce Banerdt
InSight principal investigator
Jet Propulsion Laboratory
Pasadena, California



NASA/JPL-CALTECH

NASA's Mars InSight lander will launch in March 2016 to study the Red Planet, revealing the world's interior in greater detail than ever.

Q: BLACK HOLES INHALE VAST QUANTITIES OF DUST AND GASES. DOES DARK MATTER ALSO GET CONSUMED?

Don Gensler
Umpqua, Oregon

A: Black holes capture matter through their gravitational pull. Dark matter is the name astronomers use for matter that does not interact through the electromagnetic or nuclear forces in physics, but which scientists still see through its gravitational effects. Since it interacts gravitationally, dark matter behaves no differently near black holes than any other type of matter, so black holes certainly can consume it.

Although this process sounds exotic, black holes in general relativity do not care whether they feed on regular or dark matter. The only properties a black hole has are mass, angular momentum (spin), and electric charge. Any other information carried by the material that falls into a black hole, for example what type of particle it is, is lost forever. This is called the "no hair" theorem: Black holes are completely specified by three numbers and have no extra properties ("hair"). For this reason, black holes are the simplest macroscopic objects in the universe.

The idea of information being lost from material falling into black holes is uncomfortable from a physics standpoint and as a result has long been a subject of intense debate (the "information paradox"). We hope that its resolution could be an important step toward reconciling the classical physics of general relativity with quantum mechanics.

Jason Dexter
Max Planck Institute
Garching, Germany

Q: WITH THE MOON'S TERMINATOR MOVING ALMOST 10 MPH (16 KM/H) ACROSS ITS EQUATOR, HOW LONG WOULD IT TAKE FOR AN OBSERVER USING BINOCULARS TO NOTICE A CHANGE IN LUNAR FEATURES?

Gary Garchar
San Jose, California

A: The lunar terminator, the sunset/sunrise line that sweeps

across the Moon's surface as the Moon orbits Earth, travels at a rate of 9.6 mph (15.4 km/h) along our satellite's equator. Taking the average Earth-Moon distance to be 239,000 miles (384,600km), those miles translate to an angular shift of just over 8 arcseconds per hour.

So how much time would have to elapse before binoculars could detect a shift of about 8 arcseconds? The resolving ability of a telescope is dictated by aperture, assuming high-quality optics. The low magnification of binoculars, however, usually makes that value the determining criterion.

Assuming the observer has 20/20 vision, we can estimate the minimum resolution value for binoculars by dividing its magnification into 240. Using this, we find that 10x binoculars have a resolution threshold of 24 arcseconds, while 15x binoculars can resolve 16 arcseconds, and so on.

So, given all these facts and figures, steadily mounted 10x binoculars should be able to detect a shift in the terminator after about three hours.

But that's only on the Moon's equator for when the terminator is exactly on the lunar meridian, at the quarter phases. As soon as we move off that point, then the foreshortening effect caused by the Moon's spheroidal globe comes into play. In other words, the terminator's speed slows down as you move toward the lunar poles. For the terminator's speed at other lunar latitudes, multiply its equatorial speed by the latitude's cosine.

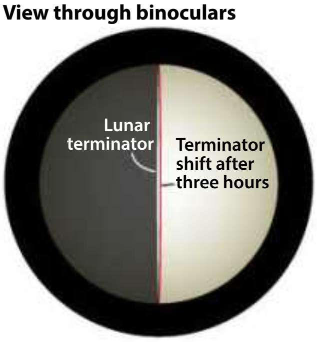
For instance, at 45° north or south lunar latitude, midway between the equator and the poles, the terminator moves at about 70 percent of its speed at the equator. At the Moon's average distance, that translates to 6 arcseconds per hour. Therefore, it would take about four hours to see the effect of motion there through our 10x binoculars.

The same would be true for a shift in longitude, either east or west of the lunar meridian.

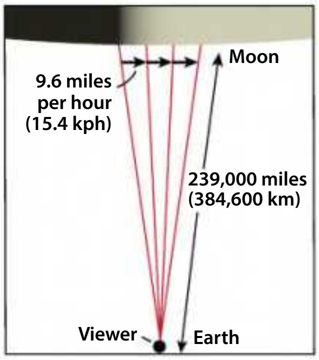
Phil Harrington
Contributing Editor

Tracking Luna

View through binoculars

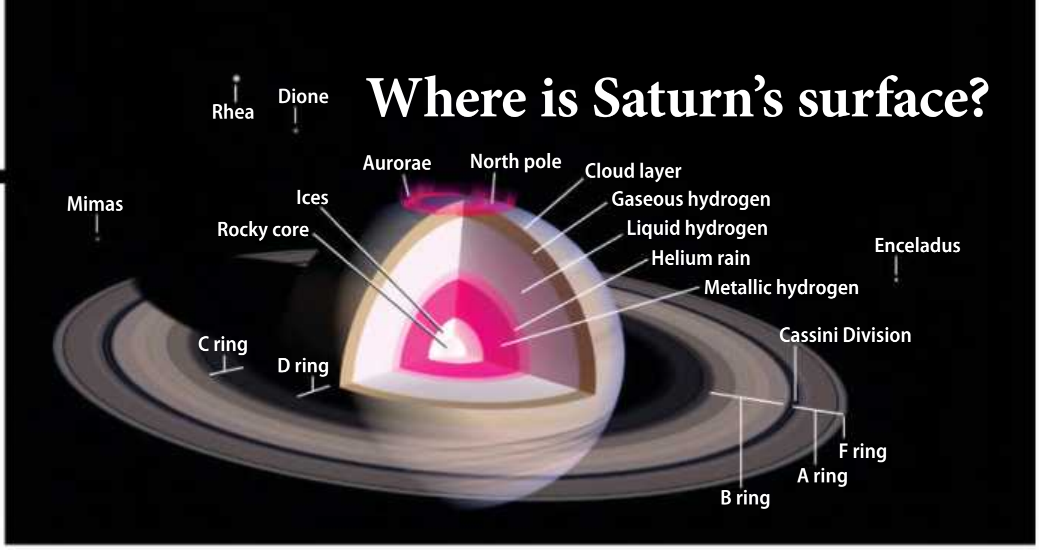


Top view looking down on Earth



The Moon's terminator appears to move about 8 arcseconds in an hour at its equator, which means it would take several hours before a viewer noticed new features using binoculars. *ASTRONOMY*: ROEN KELLY

Where is Saturn's surface?



How long is Saturn's day? Astronomers have refined the answer down to 10 hours, 32 minutes, and 44 seconds long, but identifying the giant planet's rotation hasn't been easy. *ASTRONOMY*: ROEN KELLY, AFTER KELVINSONG/WIKIMEDIA COMMONS

Q: HOW CAN ASTRONOMERS FIND A PLANET'S ROTATIONAL PERIOD WHEN THEY CANNOT SEE ITS SURFACE?

Laurence Kossmann
Dayton, Ohio

A: The rotation periods of Jupiter, Saturn, Uranus, and Neptune range from roughly 10 to 17 hours. Estimating giant planets' rotation rates, however, is not easy. Because they don't have solid surfaces, we can't infer their periods from following the reoccurring surface features. We must use alternative methods. One way is to observe the clouds and see how long it takes them to reappear (cloud tracking). But it's unclear whether clouds rotate at the same rate as the planet.

Another method is to measure how the magnetic pole rotates around the geometric pole. This method is good for Jupiter, but on Saturn these two poles are aligned, so we can't determine rotation this way. This method is also problematic for Uranus and Neptune because they have complex (non-dipole) magnetic fields.

Until recently, the best method for Saturn (and also for Uranus and Neptune) was to use spacecraft to measure the periodicity of radio radiation. Giant planets have currents that couple the magnetosphere and the ionosphere and generate radiation in radio frequencies. Recently, astronomers have found that the radio period is changing with time and therefore doesn't necessarily represent the planetary rotation. Some scientists have also suggested theoretical methods such as inferring the period from minimizing the wind speeds or inferring it from the measured gravitational fields.

In fact, another complication arises from the fact that (unlike terrestrial planets) giant planets may not rotate as solid bodies. In that case, different regions have different rotation periods (differential rotation), and there is no single period that represents the planetary rotation. Although hard to determine, the rotation period of giant planets is an important property as it puts a clear reference for the wind speeds and constrains their internal structures (core mass and bulk composition).

Ravit Helled
Department of Geosciences
Tel Aviv University, Israel

Send us your questions

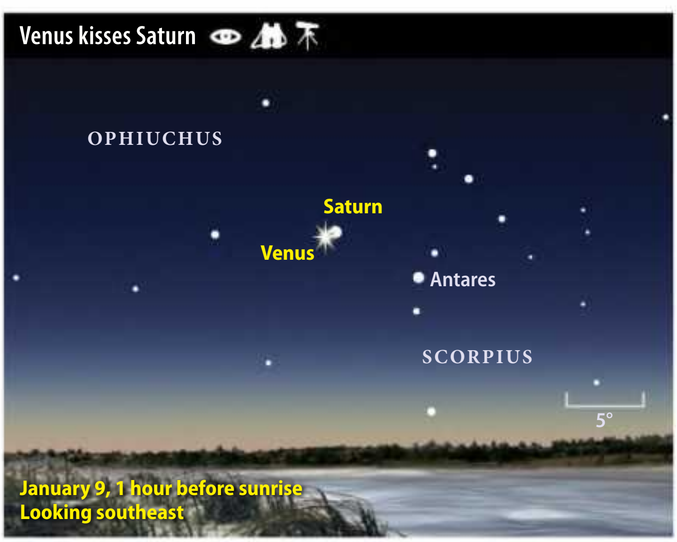
Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

MARTIN RATCLIFFE and ALISTER LING describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

January 2016: Morning sky delights

A waxing Moon forms the centerpiece of this June 18, 2007, vista that features Venus (to Luna's right) and dimmer Saturn (upper left). ALAN DYER



Venus passes within a fraction of a degree of Saturn on January 9 in their closest conjunction in a decade. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Five planets adorn January's morning sky — the same quintet of "wanderers" (Mercury to Saturn) our ancient ancestors recognized as being different from the background stars. A highlight of the month comes on the 9th when Venus passes closer to Saturn than it has in 10 years. The evening sky hosts the outer two major planets, Uranus and Neptune, which were too faint for our forebears to see.

Mercury pulls off a rare trick in January. It shows up nicely both after sunset and before sunrise. Our solar system tour begins with the planet's appearance at dusk during the month's first week. You can spot Mercury low in the southwest on the first night of 2016 when it stands about 10° high a half-hour after sunset.

The planet shows up well despite the twilight because it shines so brightly, at magnitude –0.4. If you can't spot it right way, binoculars will gather enough extra light to reveal it. When viewed through a telescope, Mercury appears 7" across and about half-lit.

The inner world fades rapidly over the next few days. Its telescopic appearance changes just as quickly — on the evening of the 5th, the Sun illuminates just 25 percent of its disk. Mercury soon disappears as it prepares to pass between the Sun and Earth on January 14. It returns to view before dawn late in the month, when we'll revisit it.

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

As Mercury dips below the horizon on the 1st, **Neptune** stands 30° high in the southwest. The outer planet glows at magnitude 7.9 against the backdrop of Aquarius the Water-bearer, some 4° southwest of 4th-magnitude Lambda (λ) Aquarii. You can spot it through steadily held 7x50 binoculars.

During January's final two weeks, Neptune lies close to magnitude 6.9 SAO 146230. This star resides a bit more than halfway along a line joining Lambda and 5th-magnitude Sigma (σ) Aqr. The planet lies 13' due west of the star on the 19th and passes 5' due north of it on the 26th.

A number of other 7th-magnitude stars populate this area, and SAO 146230 isn't the only one with an 8th-magnitude companion. To identify Neptune, point a telescope at your presumed pair and crank up the magnification. Only the planet will show a blue-gray disk that spans 2.2".

Uranus rides high in the south as darkness falls in January. Although it lies just one constellation east of Neptune, in Pisces the Fish, Uranus remains on view three hours longer than its neighbor. It makes a tempting target for observers using binoculars or a telescope.

Unfortunately, southern Pisces is devoid of bright stars, which makes it a challenge to find Uranus from light-polluted sites. Start with the Great Square of Pegasus, a conspicuous asterism even when viewed from the city.

RISING**MOON**

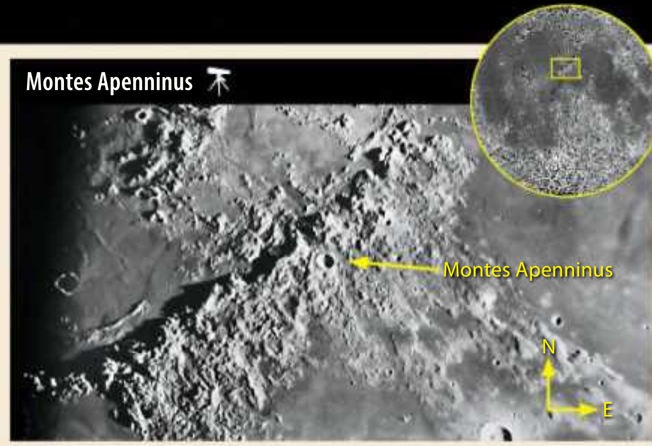
Climb every lunar mountain

A half-lit Luna is a detail-packed world of dramatic contrasts. If you observe the First Quarter Moon on January 16, you'll find a grand mountain range straddling the middle of the disk just north of the equator. Montes Apenninus (Apennine Mountains) are rugged compared with the smooth lava plains to their east. The long shadows at sunrise tell us the peaks thrust upward some 3 miles. Identify a black saw-tooth shape reaching for the nightside, then return to it every 10 minutes or so and see it grow shorter.

The spine of the Apennines curves gently to the northeast, eventually turning into Montes Caucasus (Caucasus Mountains). They also continue southwest into darkness, a region that becomes fully visible on the 17th.

Three decades after Galileo's first observations of the Moon, lunar cartographer Johannes Hevelius published a map using names inspired by European geography. The earthly Apennines form the backbone of Italy. Of the nearly 300 lunar features Hevelius labeled, however, only 10 remain today, and they are all mountains and ranges.

A century ago, observers would have been stunned to learn that the lunar Apennines are but a small section of a vast bowl some 710 miles across that formed when a hefty asteroid slammed into the young Moon. Millions of years later, the Imbrium Basin filled with lava bubbling up from the molten interior. Look closely along the shoreline and you'll see partially filled craters and blocks of rock collapsed away from the wall. Also look for wrinkle ridges — features that formed as the lava cooled and contracted — on the smoother plains that show up at low Sun angles.



The rugged lunar Apennines — the southeastern edge of Mare Imbrium — stands out at First Quarter. CONSOLIDATED LUNAR ATLAS/UA/LPL; INSET: NASA/GSFC/ASU

Draw an imaginary line that spans the 20° separating Beta (β) and Gamma (γ) Pegasi (the Square's northwestern and southeastern corners, respectively), then extend it 15° until you reach a line of three modestly bright stars. With binoculars, focus on the middle and brightest sun: magnitude 4.3 Epsilon (ε) Piscium. Uranus lies 2° south of Epsilon all month.

The magnitude 5.8 planet resides among a small group of 6th-magnitude stars, which complicates identifying the ice giant. The easiest way to confirm a sighting is to point a telescope at your suspected quarry. Only Uranus will show a disk — one with a distinctive blue-green hue that spans 3.5".

By late evening, you can find **Jupiter** climbing in the eastern sky. You'll know that it is about to appear once the figure of Leo the Lion clears the horizon. Jupiter shines at magnitude –2.3, lighting up

— *Continued on page 42*

METEORWATCH

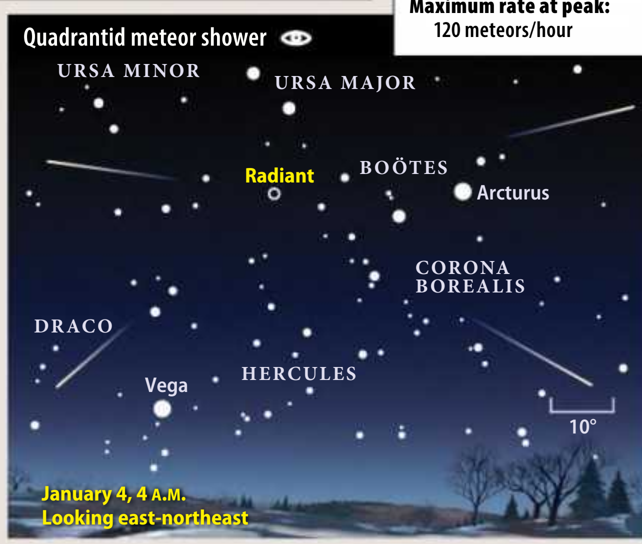
Shooting stars welcome the New Year

Quadrantid meteors

Active dates: Dec. 28–Jan. 12
Peak: January 4
Moon at peak: Waning crescent
Maximum rate at peak: 120 meteors/hour

This year's meteor calendar starts off with a bang. The Quadrantid meteor shower peaks before dawn January 4, and though a waning crescent Moon shares the sky with this prolific shower, its minimal light won't have much effect. Observers under an otherwise dark sky can expect to see up to 120 meteors per hour shortly before morning twilight commences.

Quadrantid meteors appear to radiate from a point in the constellation Boötes. Yet the shower doesn't take the name of its host constellation like most others do. In the 19th century, when astronomers first described this shower, the radiant resided in the now-defunct constellation Quadrans Muralis. The name stuck, and the only Boötid meteors now come during a relatively minor shower that peaks in late June.



This year's most prolific meteor shower could deliver up to 120 "shooting stars" per hour under ideal conditions.

The Quadrantid radiant lies in northern Boötes, below the Big Dipper's handle in January's morning sky. The area climbs high in the northeast during the predawn hours on the 4th.

OBSERVING HIGHLIGHT A waxing gibbous Moon passes directly in front of Aldebaran for observers across the United States and Canada on January 19.

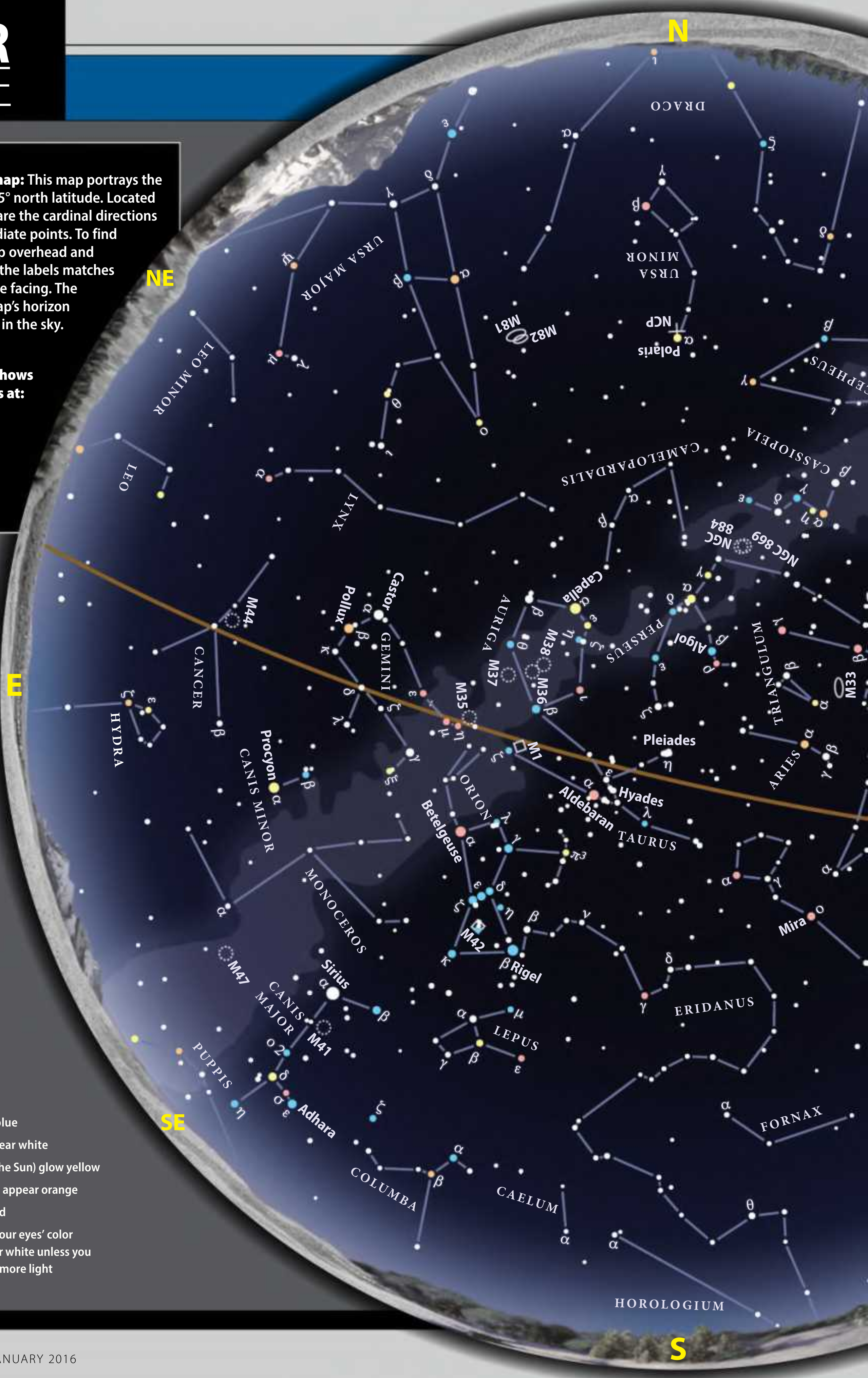
STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. January 1
8 P.M. January 15
7 P.M. January 31

Planets are shown at midmonth



STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

JANUARY 2016

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Calendar of events

2 Last Quarter Moon occurs at 12:30 A.M. EST

The Moon is at apogee (251,206 miles from Earth), 6:53 A.M. EST

Earth is at perihelion (91.4 million miles from the Sun), 6 P.M. EST

3 The Moon passes 1.5° north of Mars, 2 P.M. EST

SPECIAL OBSERVING DATE

4 The Quadrantid meteor shower peaks with only minor interference from a waning crescent Moon.

4 Mercury is stationary, midnight EST

5 Pluto is in conjunction with the Sun, 10 P.M. EST

6 Venus passes 6° north of Antares, noon EST

The Moon passes 3° north of Venus, 7 P.M. EST

The Moon passes 3° north of Saturn, midnight EST

8 Jupiter is stationary, 3 P.M. EST

Venus passes 0.09° north of Saturn, 11 P.M. EST

9 New Moon occurs at 8:31 P.M. EST

13 The Moon passes 2° north of Neptune, 10 A.M. EST

14 Mercury is in inferior conjunction, 9 A.M. EST

The Moon is at perigee (229,671 miles from Earth), 9:14 P.M. EST

16 The Moon passes 1.5° south of Uranus, 1 A.M. EST

First Quarter Moon occurs at 6:26 P.M. EST

19 Asteroid Pallas is in conjunction with the Sun, 5 A.M. EST

The Moon passes 0.5° north of Aldebaran, 10 P.M. EST

23 Full Moon occurs at 8:46 P.M. EST

25 Mercury is stationary, 2 P.M. EST

27 The Moon passes 1.4° south of Jupiter, 8 P.M. EST

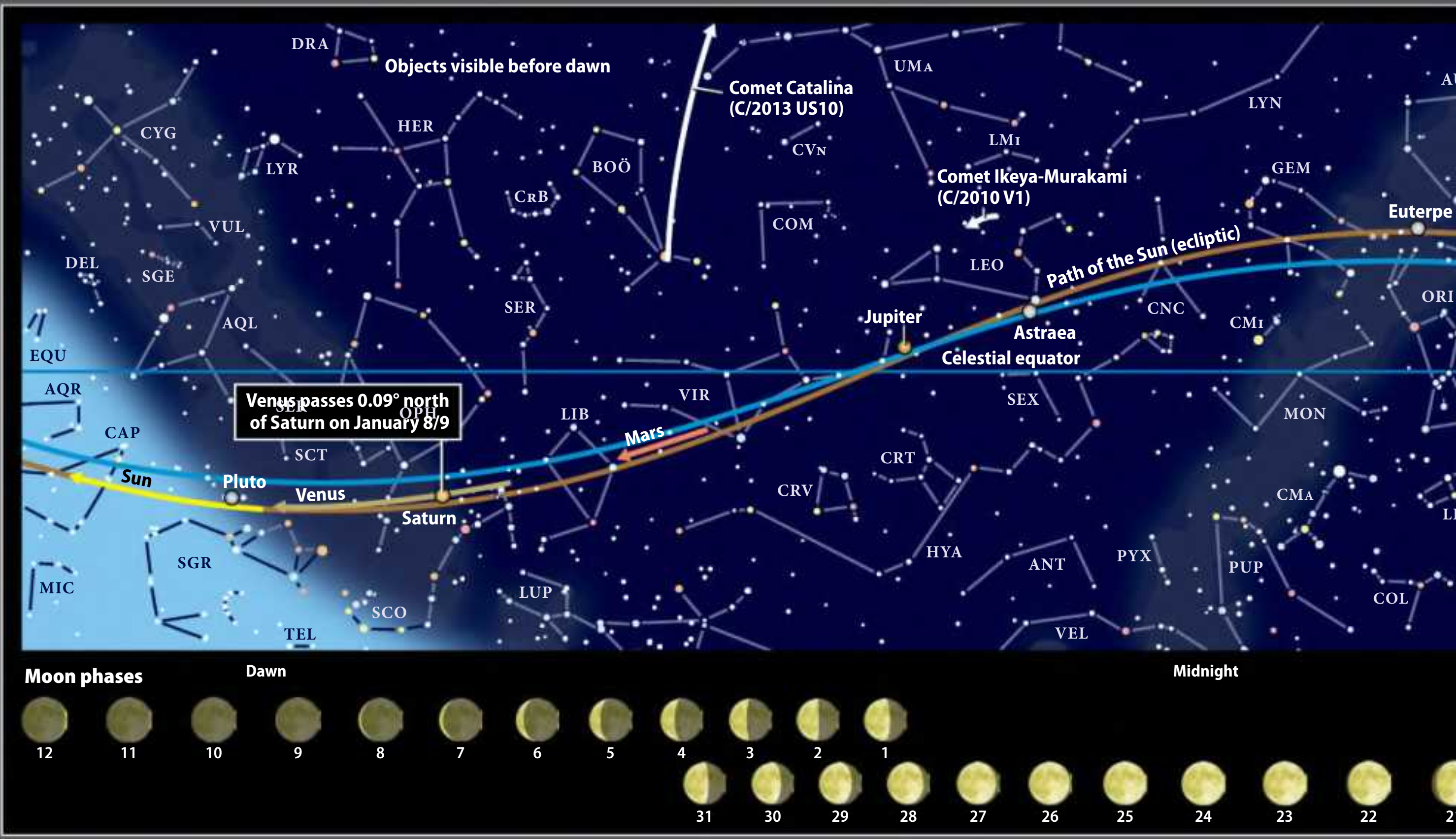
30 The Moon is at apogee (251,377 miles from Earth), 4:10 A.M. EST

31 Last Quarter Moon occurs at 10:28 P.M. EST

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

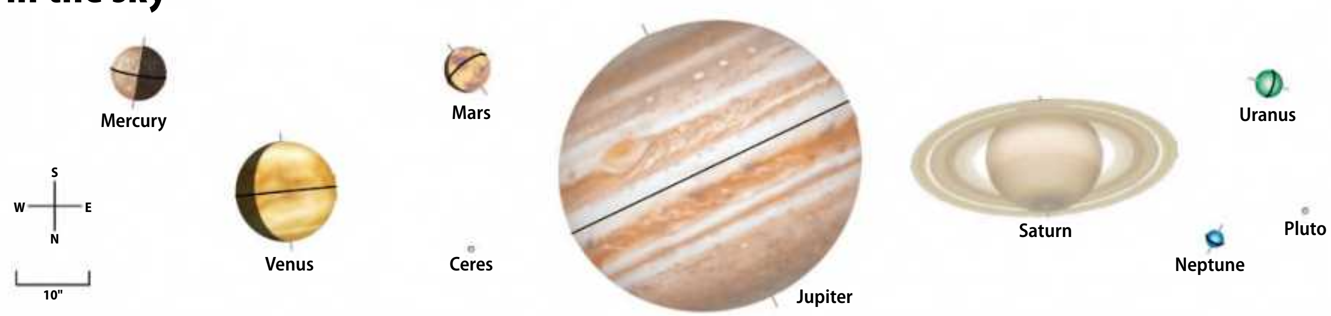
PATH OF THE PLANETS

The planets in January 2016



The planets in the sky

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets for the dates in the data table at bottom. South is at the top to match the view through a telescope.

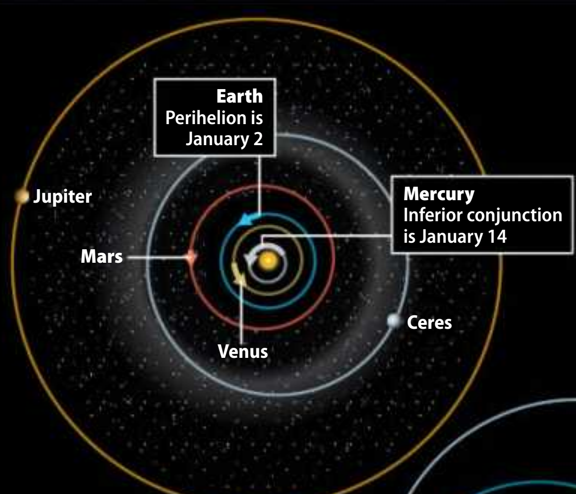


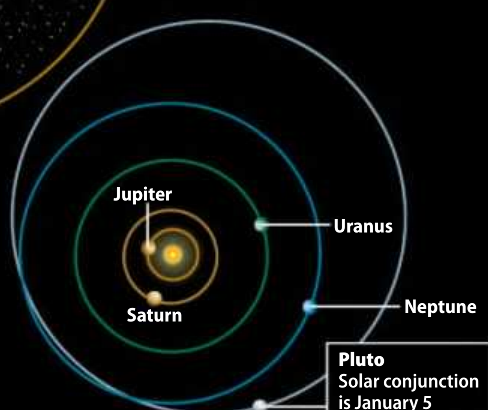
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	Jan. 1	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15
Magnitude	–0.4	–4.0	1.1	9.3	–2.3	0.5	5.8	7.9	14.3
Angular size	7.3"	13.3"	6.1"	0.4"	40.7"	15.5"	3.5"	2.2"	0.1"
Illumination	49%	81%	91%	99%	99%	100%	100%	100%	100%
Distance (AU) from Earth	0.921	1.252	1.545	3.772	4.845	10.726	20.079	30.663	33.994
Distance (AU) from Sun	0.325	0.722	1.651	2.978	5.419	10.013	19.974	29.959	33.022
Right ascension (2000.0)	20h05.5m	17h12.3m	14h16.6m	21h58.8m	11h36.1m	16h44.5m	1h01.8m	22h38.7m	19h05.7m
Declination (2000.0)	–21°06'	–21°30'	–12°06'	–20°54'	4°00'	–20°39'	5°55'	–9°25'	–21°00'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.

Early evening

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to the distance from Earth and are shown at 0h Universal Time.



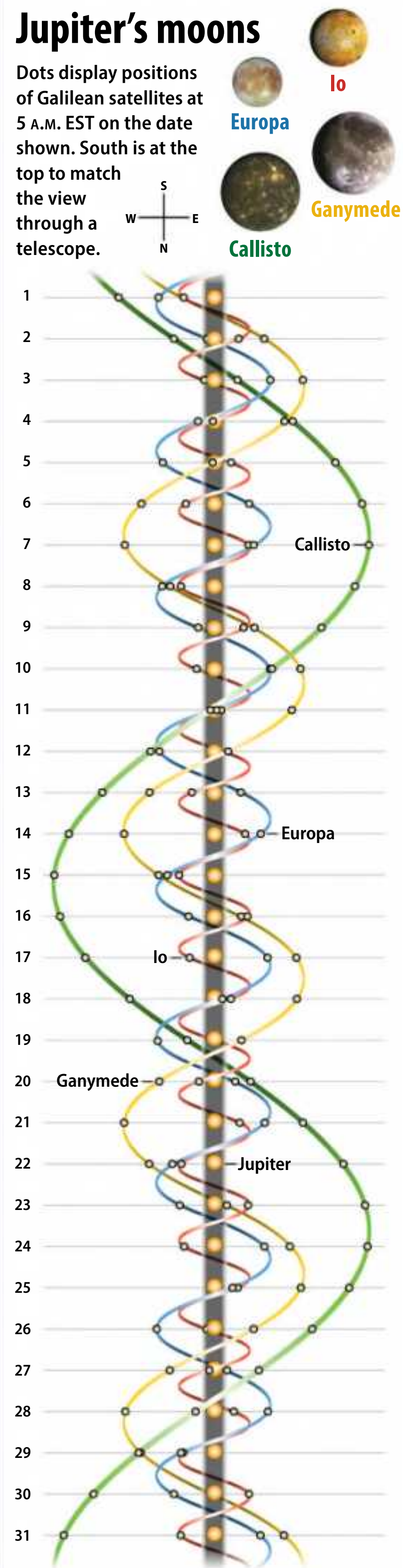


The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.

Jupiter's moons

Dots display positions of Galilean satellites at 5 A.M. EST on the date shown. South is at the top to match the view through a telescope.



ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

— Continued from page 37

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (southwest)	Jupiter (east)	Mercury (southeast)
Uranus (south)		Venus (southeast)
Neptune (southwest)		Mars (south)
		Jupiter (southwest)
		Saturn (southeast)

the rather barren background of southeastern Leo.

For observers eager to sample the planet's atmospheric wonders, wait until it climbs higher in the sky after midnight. The views won't disappoint. Jupiter's equatorial diameter swells from 39" to 42" during January, providing a large canvas for seeing cloud-top detail.

Even a small telescope reveals two dark belts, one on either side of a brighter zone that coincides with the planet's equator. Other belts and zones appear more subtle and show up best during moments of steady seeing — when the turbulent air above your head briefly settles down and telescopic images sharpen — or through larger instruments.

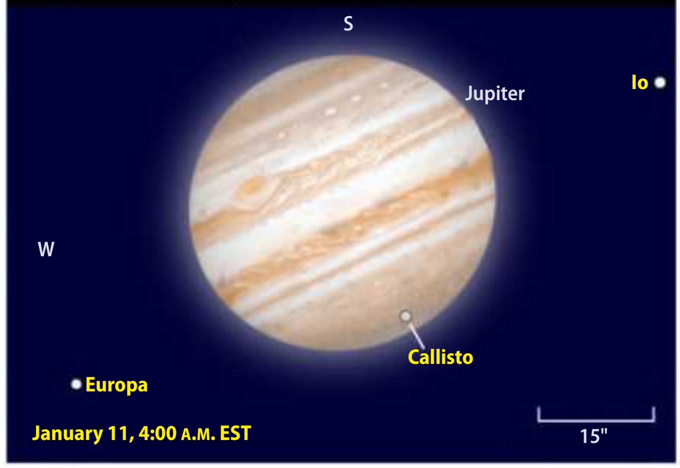
Four bright moons — Io, Europa, Ganymede, and Callisto — accompany Jupiter as it orbits the Sun. Small scopes easily reveal their nightly wanderings, which take on added interest when one of them passes in front of (transits) or behind the planet. At least one such event occurs virtually every night.

Perhaps the most intriguing series of events takes place the night of January 10/11 when three moons transit the planet in rapid succession. Europa gets the ball rolling at 11:37 P.M. EST with a transit that lasts until 2:21 A.M. Less than an hour later, at 3:04 A.M., Callisto starts to cross Jupiter's north polar region. More than halfway through Callisto's two-hour transit, at 4:22 A.M., Io's shadow falls on the cloud tops. Io itself begins to transit Jupiter at 5:27 A.M.

The parade of planets picks up once **Mars** pokes above the horizon in the early morning hours. On January 1, it rises shortly after 1:30 A.M. local time in the company of Virgo the Maiden, 6° east-northeast of that constellation's luminary, Spica. At magnitude 1.3, Mars appears slightly dimmer than the star, but what really sets them apart are their contrasting colors — the planet has a distinct ruddy hue while the star shines blue-white.

Mars moves eastward relative to the starry backdrop in

Triple the transit fun



Three moons transit Jupiter in rapid succession January 10/11, starting with Europa, followed by Callisto (shown here), and concluding with Io.

COMETSEARCH

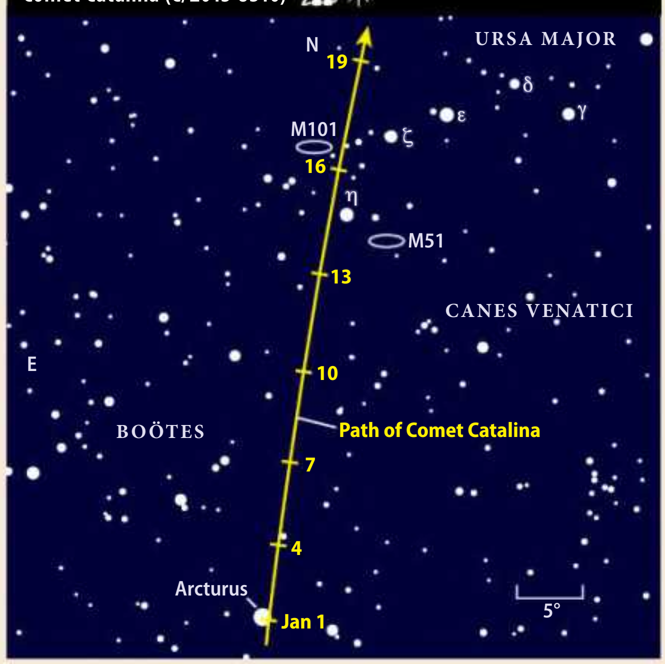
Comet skirts a bright star and galaxies

With almost perfect timing, Comet Catalina (C/2013 US10) crests the eastern horizon just after the ball drops on New Year's Eve. But can you see the 5th-magnitude comet in the glare of magnitude 0.0 Arcturus? Catalina passes within 0.5° of the star in the predawn hours of January 1. It doesn't hang around for long, however — this dirty snowball cruises northward at better than 2° per day.

The waning Moon exits the morning sky on the 7th, by which time Catalina rises before midnight. Still, your best views will come when the comet rides high in the sky before dawn. Pay particular attention from January 14–17, when this visitor from the distant Oort Cloud passes near the Whirlpool Galaxy (M51) and M101, a pair of photogenic spiral galaxies. Wide-angle images should capture the scene beautifully. Chance grants us these vistas shortly before the waxing gibbous Moon puts an end to this month's dark-sky window.

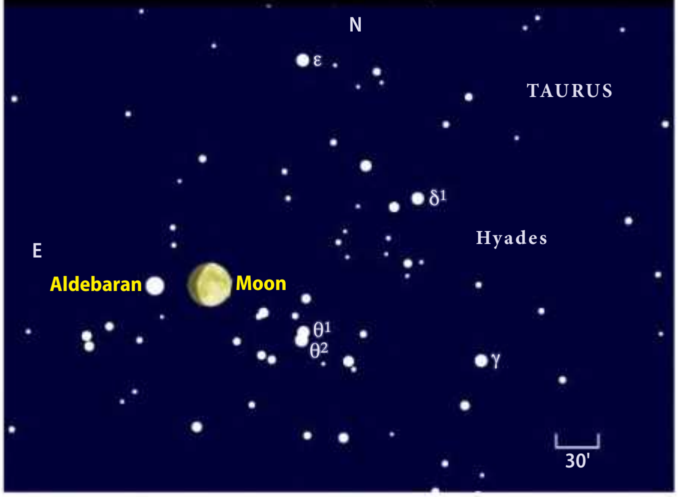
When viewed through a telescope, a 5th-magnitude comet typically sports a fair bit of detail. Use low power and sweep along the length of the tail, which should allow you to trace the comet's ejecta for several degrees. The tail's northern flank will be sharp because this is the border between the comet's ionized gas and the relative emptiness of interplanetary space. The southern flank appears softer because the dust thins out more gradually.

Comet Catalina (C/2013 US10)



This Oort Cloud visitor should reach 5th magnitude in January as it makes its way northward from Arcturus to the galaxies M51 and M101.

The Moon slides in front of Aldebaran



Most North Americans can see the Moon occult Aldebaran on January 19. This shows the scene at 8 P.M. EST, some 90 minutes before the event starts.

January, crossing into Libra on the 17th and ending the month 1.3° north of magnitude 2.6 Zubenelgenubi (Alpha [α] Librae). The Red Planet brightens considerably by then, however, shining at magnitude 0.8. Mars' rapid motion nearly matches the Sun's pace, so the world rises only about a half-hour earlier at January's close than it did on New Year's Day.

Mars was a telescopic dud during 2015 because its diameter never exceeded 5.5". That starts to change in January because the planet pulls significantly closer to Earth. By month's end, it appears 6.8" across and may start to show some subtle surface markings through larger scopes. Conditions will improve quickly this spring as Mars approaches opposition in May, when it will appear bigger and brighter than at any time since 2005.

By the time morning twilight starts to paint the sky, both **Venus** and **Saturn** appear prominent in the southeast. Venus shines brilliantly at magnitude –4.0 — the brightest point of light in the sky — but Saturn is still impressive at magnitude 0.5. On January 1, Venus lies in Scorpius and rises around 4:30 A.M. local time with Saturn in adjacent Ophiuchus following some 45 minutes later.

The gap between the two worlds closes rapidly, however. Venus skips across the narrow northern section of Scorpius in just four days, entering Ophiuchus on January 5. A pretty scene occurs the following morning when a waning crescent Moon joins the planets before dawn. Look for the Moon 7° above Venus with Saturn standing 3° below its sister world.

Three mornings later, on January 9, Venus and Saturn make their closest approach in a decade. Western Europeans have the best view, with the two planets passing just 5' apart at 4h UT. By the time the pair rises in eastern North America, 17' separate the two, and the gap grows to 25' on the West Coast. Still, both objects will appear in a single field of view through a telescope at low power. Venus shows a 14"-diameter disk that is 80 percent illuminated while Saturn appears 15" across with a ring system that spans 35".

Mercury approaches Venus at the tail end of January. The innermost planet stands 9° high in the southeast a half-hour before sunrise on the 31st, when you can locate it 7° to Venus' lower left. It shines at magnitude 0.0 and should show up clearly through binoculars. Of academic interest only, Mercury passes 0.5° north of Pluto (invisible in twilight, of course) on the 30th.

Although no planet calls Taurus home this month, the constellation does host a spectacular solar system event. On the evening of January 19, the **Moon occults Aldebaran**, the Bull's brightest star, for observers north of a line that runs across northern Mexico and the U.S. Gulf Coast. The unlit edge of the waxing gibbous Moon overtakes Aldebaran in twilight along the West Coast but after darkness everywhere else. Be sure to set up ahead of time, center the star in your telescope's field of view, and watch the magnificent show.

LOCATING**ASTEROIDS**

Take aim at the Lion's heart

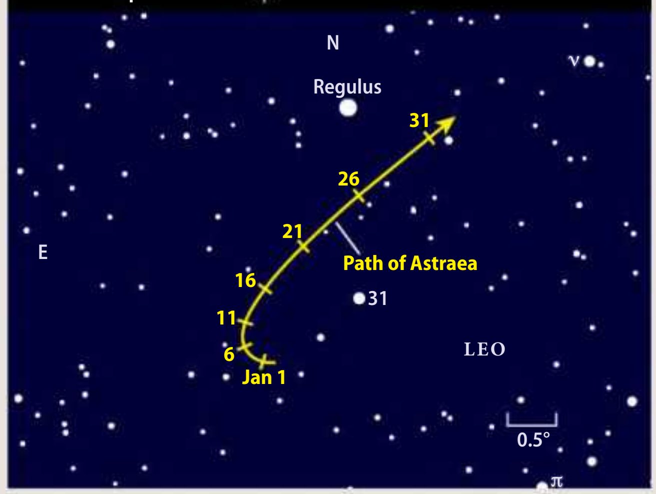
Leo the Lion rides high in the east in the late evening sky and peaks in the south after midnight. The constellation's brightest star is 1st-magnitude Regulus, a name that translates as "little king." (You'll also see it called Cor Leonis ["heart of the lion"] in reference to its position in Leo.)

This blue-white luminary serves as the starting point for locating asteroid 5 Astraea. The minor planet passes 1° due south of the star January 25 but pulls even closer (0.75° away) a few days later. Astraea glows at 9th magnitude and should be easy to pick out from the starry backdrop near Regulus.

Use the chart below to home in on the asteroid earlier in the month. Fourth-magnitude 31 Leonis serves as a nice secondary anchor. None of the background stars near Astraea's path are as bright as the asteroid, so identifying it should be a snap.

German astronomer Karl Hencke discovered Astraea in December 1845. In the nearly 40 years after Vesta's 1807 discovery, most astronomers were convinced that just four objects existed between the orbits of Mars and Jupiter, and many considered them planets. Astraea's discovery triggered their downfall from planethood and ushered in the age of asteroids.

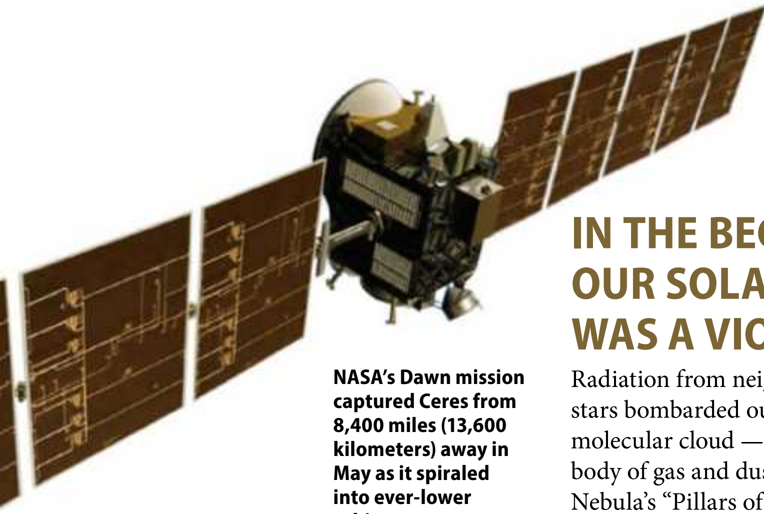
Leo hosts a planet killer



Look south of Regulus to find 9th-magnitude Astraea. This asteroid, the fifth to be discovered, destroyed the planetary status of the first four.

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

Dawn mission reveals



NASA's Dawn mission captured Ceres from 8,400 miles (13,600 kilometers) away in May as it spiraled into ever-lower orbits. ALL IMAGES: NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA, EXCEPT WHERE NOTED

IN THE BEGINNING, OUR SOLAR SYSTEM WAS A VIOLENT PLACE.

Radiation from neighboring massive stars bombarded our small part of a large molecular cloud — a many light-years-wide body of gas and dust resembling the Eagle Nebula's "Pillars of Creation" — as the whole expanse coalesced like a figure skater pulling her limbs in tight for a spin.

Some 99.8 percent of the mass drew to the center, forming our Sun. And out of the firmament 4.6 billion years ago, tiny bits of dust, like particles in a smoke cloud, stuck together to create ever-larger clumps.

Grains grew into pebbles; pebbles formed planetesimals.

But this process was still in its early days when a supernova blast rang out, seeding radioactive elements across the still-forming inner realm of planets, which trapped heat inside any worlds already gathered together.

Meanwhile, something pivotal took place between 2 and 3 astronomical units from our young Sun (1 AU is the average Earth-Sun distance) in the present-day asteroid belt. As Jupiter, the largest planet, took shape, it had catastrophic effects on a group of planetesimals.

The gaseous giant perturbed the region and stopped its mass from ever coalescing to become a terrestrial planet.

Jupiter may have flung much of the mass to the solar system's outer reaches, leaving what's now called the asteroid belt with a mass equivalent to just 4 percent of that contained in Earth's Moon. What was left is what we still see today.

One-third of that mass is held by a single world, Ceres. At 590 miles (950 kilometers) across, it's our solar system's largest asteroid and the only dwarf planet this side of Pluto. It's also a relic of our violent origins.

This icy body is the current focus of NASA's Dawn mission — a small spacecraft that's powered its way across the inner solar system since 2007 using unconventional ion propulsion. The engine allowed Dawn to become the first mission to ever orbit two extraterrestrial bodies. Astronomers spent 14 months studying the asteroid Vesta before embarking for Ceres in 2012.

"Ceres, and Vesta before it, are intact protoplanets — bodies that were growing to planethood when their growth was stopped by external forces," says Dawn Principal Investigator Chris Russell of the University of California, Los Angeles. "They have a record of the earliest days of the solar system. They were there and experienced it and have evolved little. ... We are returning to the scene of the crime to interview the witnesses."

Now, these fossil planets are teaching astronomers what our solar neighborhood was like when Earth saw its first sunrise.

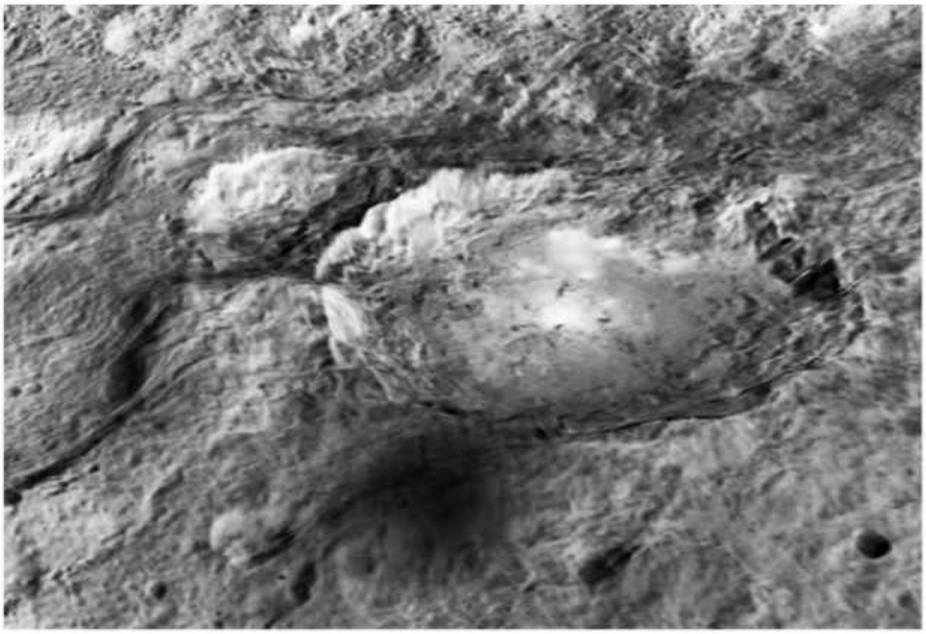
Solar system models use bodies like Vesta and Ceres as building blocks for terrestrial planets. Ceres is likely similar to the planetesimals that brought Earth its oceans. And our planet's iron core might have formed from a number of Vesta-like worlds.

"Almost everything we see on Ceres was unknown before we arrived," Russell says. "Ceres had kept its secrets well."

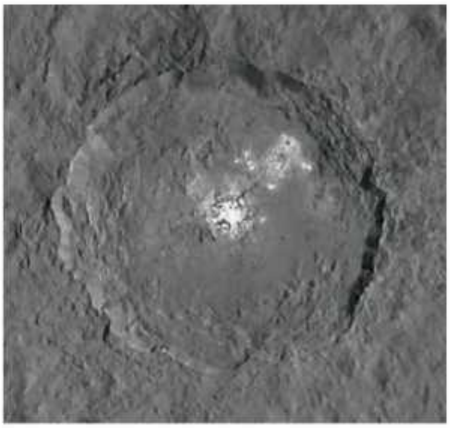
Eric Betz *is an associate editor of* Astronomy. *He's on Twitter: @ericbetz.*

dwarf planet Ceres

With lowlands, highlands, weird white spots, and even a pyramid, the largest object in the asteroid belt is unlike anything else in the solar system. **by Eric Betz**



Occator Crater spans 50 miles (80 kilometers) from rim to rim and is home to Ceres' brightest spots. After months of intense speculation, Dawn scientists now believe they understand what causes them.



Ceres' most intriguing features are the dwarf planet's mysterious white spots, which astronomers now say are salt deposits.

An active protoplanet?

As Dawn neared Ceres in early 2015, something truly unexpected emerged in its imagery — two weird white spots. The bright areas, which shine almost like a cat's eyes when seen from afar, have remained the fossil planet's most intriguing features. Astronomers believe that unraveling their mystery could explain what's happened to Ceres since its growth was stunted all those billions of years ago.

Vesta's relative abundance of radioactive aluminum-26 (Al-26), known from meteorites commonly found on Earth and traced back to the asteroid, tells astronomers that the asteroid formed in the solar system's earliest days. Vesta was blasted by the supernova shock wave, and the radioactive isotopes generated heat in the planetesimal and vaporized its water.

But astronomers had to visit Ceres to fully understand its past. Unlike Vesta, the icy body didn't create a family of rocky meteors to help tell its story.

However, current theory holds that Ceres was slightly farther out in the solar system, so it took shape later — maybe only a couple million years later. And planetary scientists think that relatively short time span could have made all the difference, because Al-26 decays quickly.

So, Vesta lost its water and was left with differentiated layers of rock and iron like a terrestrial planet or Earth's Moon. But snowball Ceres clumped together more like an icy outer moon or Kuiper Belt object — Pluto's smaller cousins beyond Neptune's orbit.

In fact, the resemblance between Ceres and newly revealed Pluto is so strong that Dawn team members have been left scrambling for answers.

Michael Bland is on the Dawn team and an astronomer at the United States Geological Survey (USGS). He says he expected Ceres to have a smoother surface with fewer pristine craters. Instead, that description better fits Pluto.

"Pluto looks a lot like what I expected Ceres to look like, and Ceres looks like how I expected Pluto to look," Bland says. "It's like someone switched them on us."

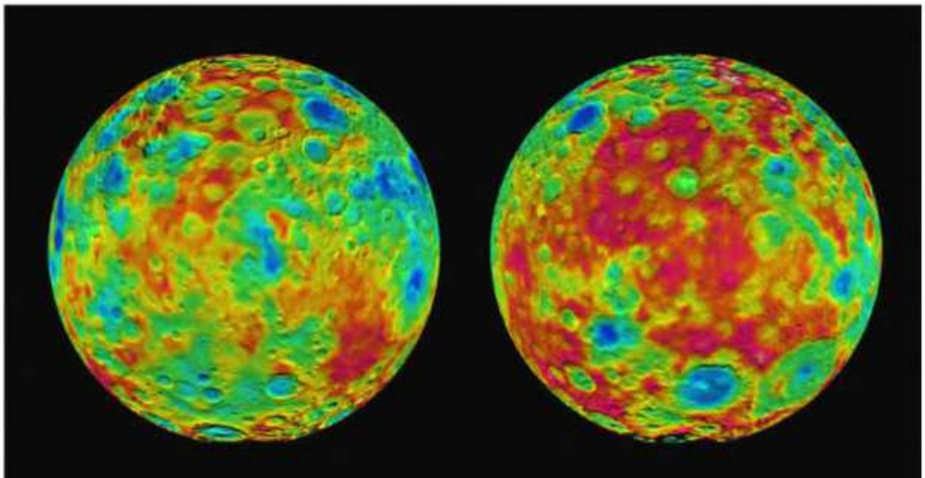
And while high-resolution data has only just begun streaming home from the Dawn spacecraft, astronomers must now try to explain how oddball Ceres has evolved.

"The question is whether Ceres is active like Pluto, or whether Ceres was once more active like Pluto and it lost its surface volatiles because it's closer to the Sun," says Dawn mission scientist Vishnu Reddy of the Planetary Science Institute in Tucson.

Reddy and a team of astronomers think they may already have found some clues. In early 2014, the European Space Agency pointed its Herschel Space Observatory at Ceres and caught water vapor streaming from two small regions. Reddy says that the areas are now known to coincide with the white spots.

Dust rains onto everything in the asteroid belt, turning surfaces a darker shade of gray. So, the white spots are younger than the rest of the surface. But just how young is anyone's guess.

Astronomers don't know how much dust falls onto the world. If the white spots are truly young, it's possible that the Herschel telescope caught some sort of icy eruption from Ceres' subsurface.



Fresh topographic maps of Ceres' hemispheres highlight elevation differences across the dwarf planet. Here high points are shown in red, and lower elevation features are blue.

White spots explained

At first, scientists speculated the white spots could be excavated water ice, salt, or clay. And determining which they were turned out to be tougher than expected.

"We didn't like the ice explanation, but we felt we were being driven to that explanation by how bright the surface was," Russell says.

At nearly 3 AU from the Sun, Ceres, unlike distant Pluto, is bombarded by sunlight, and that would cause any surface ice to quickly turn to gas via sublimation.

But then as Dawn flew over the white spots in its survey orbit, the spectra instrument shut itself down. When that happens, all the data are dumped. Astronomers would have to wait to find out.

Irrefutable evidence finally came as Dawn descended into its science orbit and sent back better images. Dawn's photos showed that the white spots are actually far bigger than expected. That meant salt, which reflects less light than water ice, was the only likely solution. And when NASA finally got spectral data, it confirmed salt's chemical fingerprints. The white material has now been detected covering peaks and crater rims across the dwarf planet.

"Definitely [the white spots] can't be ice," Russell says. "We've got enough spectra from them to see they don't have the absorption bands that we would expect ice to have."

Extraterrestrial bath salts?

That also better aligns with what astronomers are seeing elsewhere on the Texas-sized body. While scientists believe Ceres' interior is packed with water ice and even possibly a liquid ocean, the surface is dry. However, that doesn't mean there's never been ice at the surface or even in the white spots.

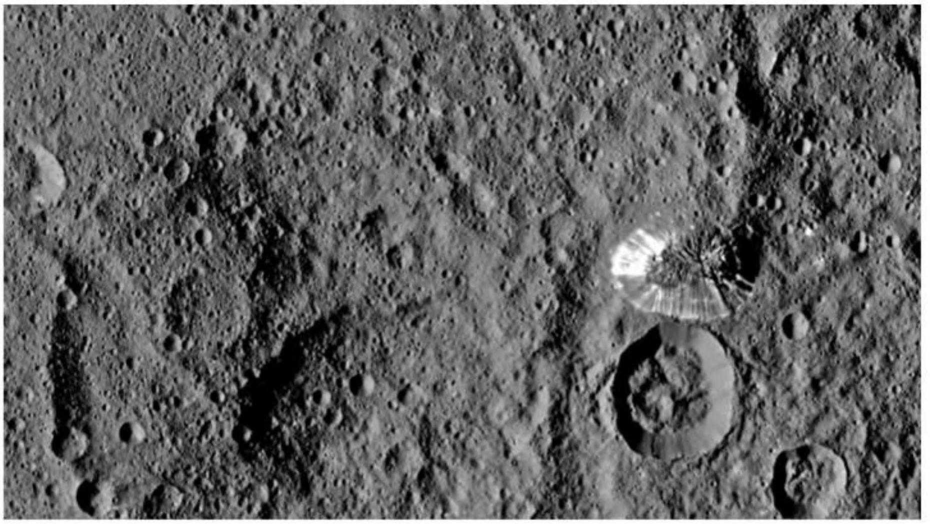
"Water vapor could temporarily freeze to form water ice that would sublimate and leave the salt behind," Reddy says. "This is the story we have for now. We don't have the spatial and spectral resolution to rule out the presence of water ice as a minor component."

Salt was expected on the dwarf planet, but its extent has surprised scientists.

"On Ceres, it seems like the presence of salts may be important for understanding even the basic morphology and what we see on the surface," Bland says.

The Dawn team is now trying to understand the salt's source. Does Ceres have many kinds of salts, or are the deposits connected? Russell suspects the latter.

"The most obvious explanation to me is that there is a fluvial connection down below the surface that connects all of these regions together like an aquifer," Russell says. "Maybe you can't get from one place to another, but the chemistry is the same."



Ceres' lone mountain vaults some 4 miles (6 kilometers) above the surrounding surface, making it taller than even Denali, North America's highest summit.

He thinks spectra will eventually show that the salt covering Ceres' mountain is the same stuff that covers the craters.

The salt forms in the world's interior, and depending on the acidity of water below the surface, models indicate that this salt could be one most earthlings are familiar with: magnesium sulfate, also known as Epsom salt. The popular bath salt is found across our planet and on other worlds too.

Collisions are common in the asteroid belt, and Ceres has the craters to prove it. What's most surprising is that the dwarf planet has remained so intact throughout our solar system's history.

The great pyramid of Ceres

Salt isn't the only revelation at Ceres. The dwarf planet hosts a lone mountain that vaults more than 21,000 feet (6,400 meters) off the surface, a height greater than even Denali, North America's highest peak.

"The team is totally baffled by the mountain at the present time, and it's going to take more than just great pictures because we just don't see the sort of manifestations that we would expect for mountain growth," Russell says. "We have to sort of think: What would you expect around a mountain on Earth?"

So far, there's nothing earthly about it. At first, scientists wondered if something fell from space and created the odd mountain. Neighboring Vesta sports one of the highest mountains in the solar system, but it's surrounded by an obvious impact that ejected much of the asteroid's south pole into space, creating the body of meteorites commonly found on Earth.

However, Ceres' mountain is not surrounded by any obviously related impact. And the peak is made from the same material as the rest of the dwarf planet — not some alien substance.

The next best idea was that the mountain is actually a volcano. But after scouring the solar system for similar volcanoes, the team has yet to find anything like it.

New Horizons' Pluto flyby on July 14 complicated things even more when it showed Ceres isn't the only dwarf planet in the solar system with mountains.

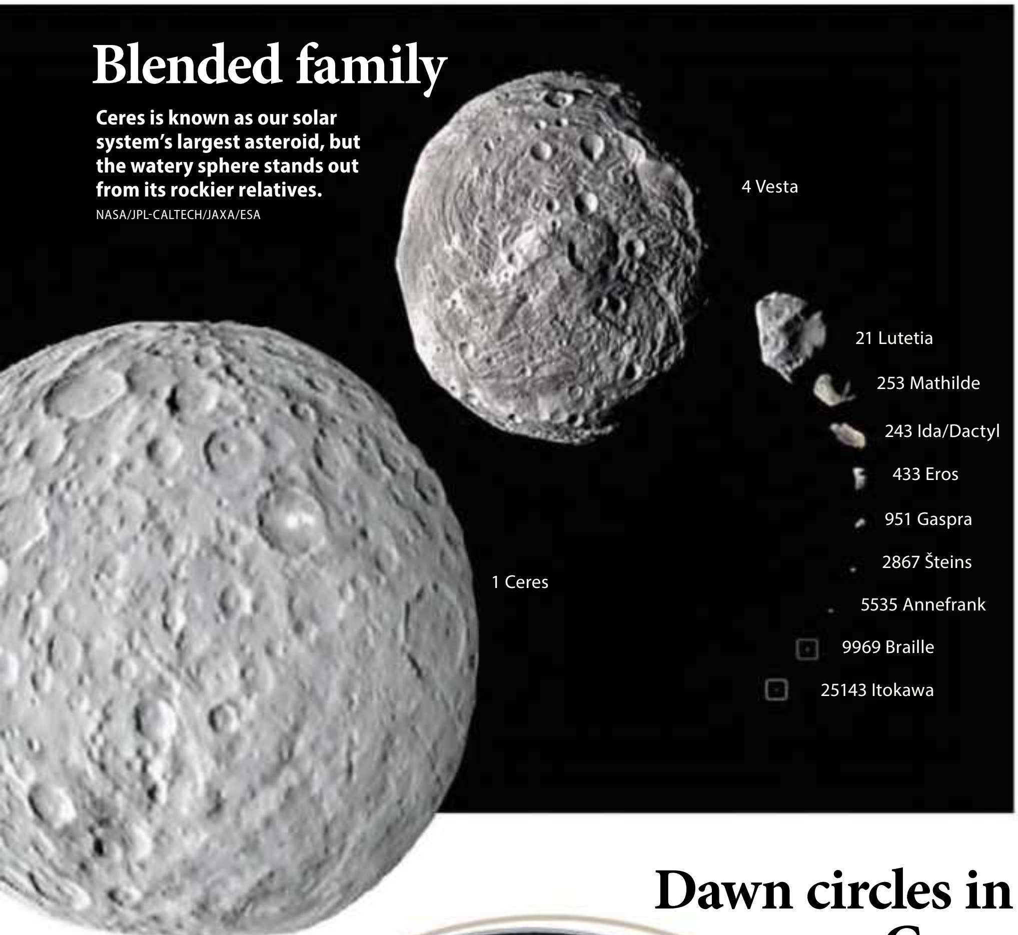
Pluto has many ranges that sweep across its complex surface, including in its light-colored "heart," informally known as Tombaugh Regio.

Scientists say these mountains must be made of water ice — a substance also abundant on Ceres. But so far, astronomers haven't found any way to link the mountains on the two bodies.

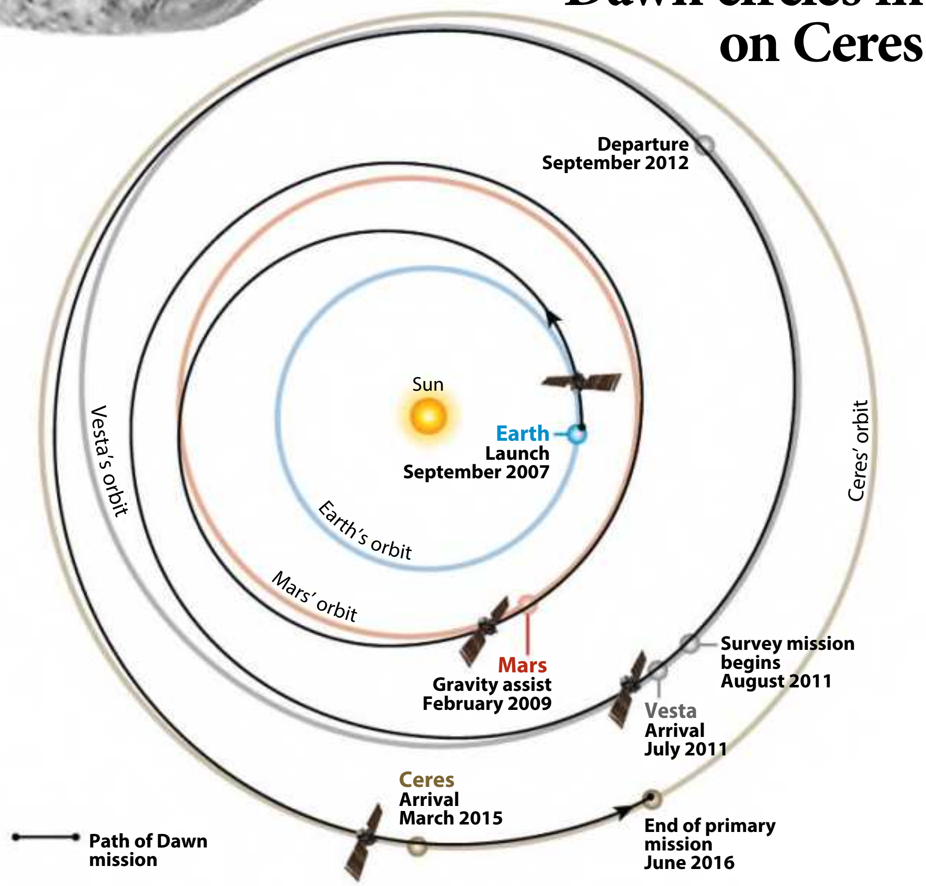
"The heights of [Pluto's] mountains and the shape of the mountains look very similar to the shape of our mountains," Russell says.

Blended family

Ceres is known as our solar system's largest asteroid, but the watery sphere stands out from its rockier relatives. NASA/JPL-CALTECH/JAXA/ESA



Dawn circles in on Ceres



After launch in 2007, Dawn got a gravitational assist from Mars to reach orbit around Vesta, where the spacecraft spent 14 months before departing for Ceres. Dawn is now the first human-made object to orbit two different extraterrestrial worlds. *ASTRONOMY*: ROEN KELLY, AFTER NASA

"There is a story there, but we haven't figured out what the answer is. We believe these bodies formed in very different parts of the solar system. Is there a way they could have been much closer together originally?"

For now, the mission head says, the formation of Ceres' mountain is the most common topic of conversation.

Ceres' thin crust

Even though much of Ceres' surface remains unexplained, astronomers already have named the most prominent features.

Fresh topographic maps from the Dawn team highlight elevation changes as great as 9 miles (15km) between the crater bottoms and mountaintops. Kerwan Crater, named for the Hopi god of corn growing, is Ceres' largest confirmed crater at 175 miles (280km) from rim to rim. That makes it roughly the same size as Earth's largest well-established impact site, South Africa's 2-billion-year-old Vredefort Crater. Kerwan bottoms out some 3 miles (5km) below the surrounding surface. And while the other craters are significantly smaller, they all look like those seen much farther out in the solar system.

"The craters we find on Ceres, in terms of their depth and diameter, are very similar to what we see on Dione and Tethys, two icy satellites of Saturn that are about the same size and density as Ceres. The features are pretty consistent with an ice-rich crust," says Paul Schenk of the Lunar and Planetary Institute in Houston.

This backs up the idea that Ceres' composition has much more in common with well-known icy moons than it does with its asteroid belt neighbors. And yet the dwarf planet is also different from the icy moons.

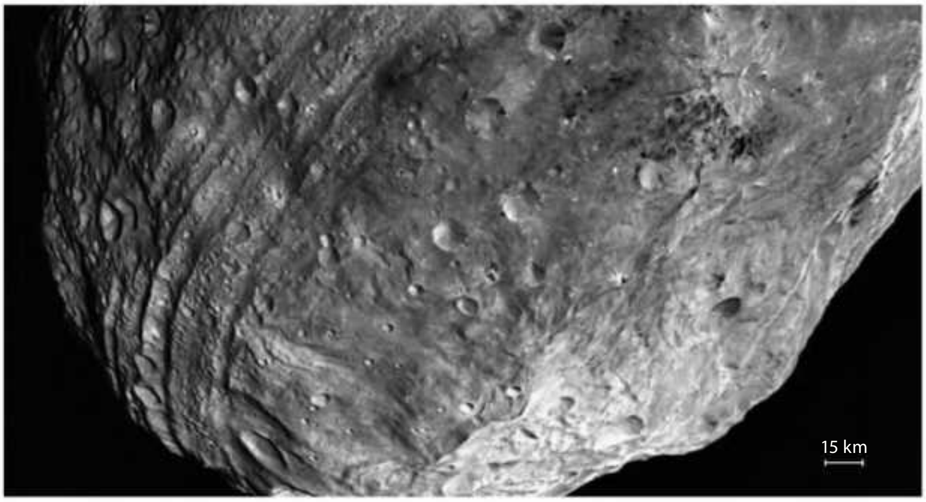
Some of its craters look like those seen where ice is abundant on Mars. These so-called central pit craters form when an impact melts ice and it flows away at the center, leaving a depression. This implies a mix of both rock and ice, but astronomers are still trying to understand the ratio.

"Ice seems to be an important component, but the surface is very, very dry," Russell says. "Paradoxically, the surface tells us [Ceres] must have been wet at some time. It looks like the morphology of wet areas on Earth."

The new icy dwarfs

And in a question similar to the one faced at Pluto, scientists are trying to determine if Ceres has a liquid water ocean beneath its dirty surface. So far, the Dawn team

Dawn's unconventional ion engine allowed it to slowly spiral into orbit around Ceres in March.



A deep chunk is missing at the south pole of Vesta, the Dawn mission's previous target. Astronomers believe this rocky mass supplied the family of asteroids commonly found as meteorites on Earth.

hasn't confirmed the water vapor that the Herschel telescope saw around Ceres. Yet astronomers say they do believe the space observatory's results.

USGS astronomer Timothy Titus is a participating scientist in the Dawn mission. His models show that water ice isn't stable within a few meters of the surface at Ceres' equator.

And that's where the world's white spots are. Instead, Titus says water could more easily flow in the polar regions. Before Dawn's arrival, Bland, the other USGS astronomer, published a paper outlining how Ceres' craters would relax if the dwarf planet had an internal ocean.

So far, the crater edges all look pretty crisp. If there's water, it's not very close to the surface.

"The idea of cryovolcanism in the outer solar system is not new, and it's been applied to a lot of the ice giant moons because there you can get tidal heating," Titus says. "At Ceres, you don't have that."

Instead of the pull from a massive host planet, Ceres — as well as Pluto — might still have enough internal warmth to drive its surface activity. And some astronomers have begun to question whether long-lived radioactive isotopes could still be driving heat all these billions of years later.

Titus suspects that Ceres' surface is more Mars-like and that asteroid impacts excavate water ice, which sunlight evaporates, leaving only the salt deposits.

Whether plumes, impacts, or something else cause the white spots, Ceres and Pluto have already rewritten what was thought possible for geological activity on such small isolated bodies.

And, in December, Dawn descends into its lowest orbit — just 233 miles (375km) above Ceres' surface. From that vantage point, astronomers can use the spacecraft's Gamma Ray and Neutron Detector to map elements, including salt, and gain new insights into the dwarf planet's evolution. Its primary mission wraps up in June 2016.

"[Dawn] has validated the origin of the solar system that was deduced from the meteorites," Russell says. "But that is not the whole story. We had to explore Ceres to obtain its secrets."

LEARN MORE ABOUT DAWN'S FINDINGS AT VESTA BY VISITING **www.Astronomy.com/toc.**

Brief biography

Today, Hawking is one of the world's leading thinkers on cosmology and the history and evolution of the universe. ANDRÉ PATTENDEN/COURTESY STEPHEN HAWKING

The life and times of

Stephen Hawking

Next summer's Starmus Festival will constitute a once-in-a-lifetime tribute to the great theoretical physicist. **by David J. Eicher**

All of us astronomy types owe a lot more to Stephen Hawking than I think most of us realize. He has been at the forefront of thinking on cosmology, gravitation, black holes, and related subjects for many years.

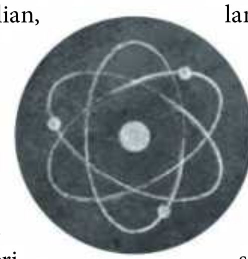
Many of us know that Hawking had for years, until 2009, held the Lucasian Professorship of Mathematics at the University of Cambridge, the same chair occupied 300 years earlier by Isaac Newton. Just a few years ago, Hawking founded and became the first director of the Centre for Theoretical Cosmology at Cambridge.

Most of us know his life story reasonably well, particularly in the wake of the 2014 film *The Theory of Everything*, which depicted his struggle for knowledge and survival. The movie brought home an Academy Award for actor Eddie Redmayne. Obviously, Hawking's story of triumph and brilliance is deeply intertwined in the public perception with his debilitating motor neuron disease, diagnosed in 1963 when Hawking was 21 years old.

That such a combination of sheer brilliance exists in a body that has withstood an incredible attack of nature is overwhelming and inspiring to us all.

Knowing that you're in the room with perhaps the smartest human being on the planet is an amazing experience. Last year, Hawking attended the Starmus Festival in the Canary Islands, the unique gathering of science enthusiasts that features talks by Nobel Prize winners, astronaut-explorers, science communicators, and researchers, as well as celebrations of music, art, and life on Earth. He delivered two incredible talks, one on the creation of the universe and the other on black holes. He sat near the front in the audience during my talk about recent astronomical advances and the communication of science to the public. Trust me, there is a magnetic feeling one has when Hawking sits close by.

Now, a year later, we are both on the Board of Directors of the Starmus Festival. And I am proud to say that due to the herculean efforts of Garik Israelian, the founder and director of Starmus, that next year, in June 2016, the third Starmus Festival will take place, again in the Canaries. And this time it will constitute a major tribute to Stephen Hawking, his life and times. It will be an experience in the world of astronomy, cosmology, physics, and entertainment like no other that has come before it.



Despite all we know about Hawking, there is something more there. Something almost magical. Let me explain.

Humble beginnings

Stephen William Hawking was born January 8, 1942, in Oxford, England, in the midst of World War II and the ongoing blitz bombing by the Nazis. He was descended from a line of tenant farmers, his father being the first to attend college, at Oxford, where he studied medicine. His mother was the daughter of a Scottish doctor. To the day, Hawking was born 300 years after Galileo's death. At first, however, no one suspected he would become attached to the heavens.

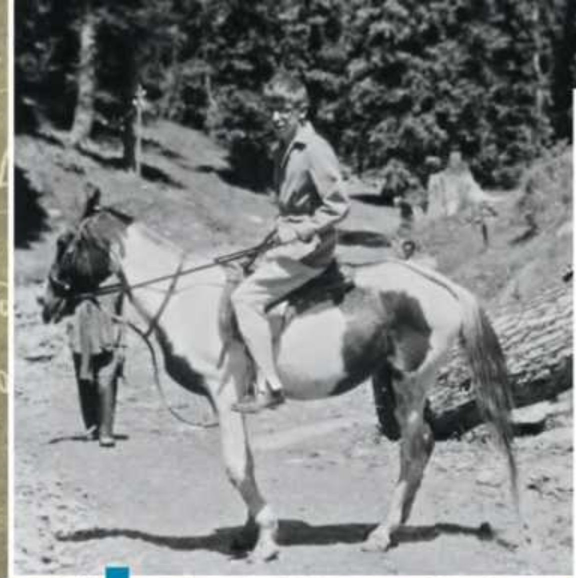
The family had spent time in Oxford rather than always staying home in London because the former was off-limits for Nazi bombing, along with Cambridge (as were the German university towns of Heidelberg and Göttingen). In Highgate, North London, the Hawking family grew. "My earliest memory is of standing in the nursery of Byron House School in Highgate and crying my head off," Hawking says in his memoir, *My Brief History* (Bantam, 2013). Discomfort from being left with strangers splayed against the trauma of an occasional bomb dropped nearby. "A V-2 rocket landed a few houses away from ours," he says.

Hawking grew up enjoying his train set and later built model airplanes and ships. After the war, in 1950, the family moved to St. Albans, 20 miles north of central London, so that Hawking's father could be close to the newly opened National Institute for Medical Research, where he studied tropical diseases. In St. Albans, "the family was regarded as eccentric," says Hawking. The Hawkings weren't poor, but they were of relatively modest means.

Education in England was very hierarchical, and Hawking did well enough to be classed fairly high but stayed in public schools. During the last portion of his normal schooling, he became interested in mathematics and physics. Physics,

1942

Stephen William Hawking was born January 8, 1942, in Oxford, England, to Frank, a medical researcher, and Isobel, a secretary. COURTESY STEPHEN HAWKING



1950s

As a teenager, Hawking enjoyed horseback riding, but his true fascination was with understanding how things worked. He frequently took items apart, though he admits he wasn't as good at putting them back together. COURTESY STEPHEN HAWKING

1960s

On entering graduate school at Cambridge University in 1962, Hawking chose cosmology and gravitation over particle physics, feeling that "the study of elementary particles at that time was too like botany," according to his memoir. He spent much of his 20s working with Roger Penrose and Bob Geroch on general relativity. COURTESY STEPHEN HAWKING

Hawking thought, was somewhat boring "because it was so easy and obvious." But physics and astronomy offered the hope of understanding the meaning of it all. "I wanted to fathom the depths of the universe," he says.

How to make a physicist

In 1959, at age 17, Hawking took an entrance exam for Oxford. He received a scholarship and commenced schooling there, in his third year joining the boating club as a coxswain in order to make more friends. He didn't work particularly hard, averaging an hour of studying per day, but that was the prevailing attitude then at Oxford. One should rely on brilliance. Despite that, he advanced successfully to graduate school.

In October 1962, Hawking arrived at Cambridge as a grad student, having applied to work with the great astronomer and cosmologist Fred Hoyle. He ended up working with Dennis Sciama and was excited by the prospects of cosmology and elementary particle physics. Particle physics was in a strange period of research, so Hawking gravitated toward cosmology and gravitation, two seemingly neglected fields that offered lots of opportunity.

Hawking joined the battle to expand the understanding of general relativity just as that movement was gaining momentum. During his last year at Oxford, however, he noticed increased clumsiness. He saw a physician after falling down some stairs, and the doctor merely warned him to "lay off the beer." But while skating on a frozen lake at St. Albans, he fell and could not get back on his feet. Just after his 21st birthday, Hawking entered a hospital for tests.

The doctors at first were not too communicative, but soon Hawking was diagnosed with an incurable, rare type of a motor neuron disease in the vein of ALS, "Lou Gehrig's disease," that has since paralyzed him. "The realization that I had an incurable disease that was likely to kill me in a few years was a bit of a shock," says Hawking. That is certainly something of an understatement. Some of the doctors initially thought he would only live for a couple years. That was 52 years ago, and he is still going strong.

Marriage and family

Hawking had met Jane Wilde, a friend of his sister's, just before his diagnosis, and the two wanted to get married. If so, he would need a job. And for that, he would need to finish his Ph.D. Set against the background of an uncertain future, Hawking thrust into high working gear for the first time. Hawking was inspired by Roger Penrose, who hypothesized spacetime singularities in the centers of black holes, and applied this thinking to the entire universe in his Ph.D. dissertation, which he completed in 1966. Meanwhile, the previous year, he married Jane.

The Hawking family grew. Son Robert was born in 1967, daughter Lucy in 1970, and later, another son, Timothy, in 1979.

At the tail end of the 1960s and throughout the 1970s, Hawking worked tirelessly on gravitational waves and their likely sources (black holes), on the confirmation of the Big Bang theory, and on a theory of causal structure in general relativity, and became increasingly interested in black holes. A few days after the birth of his daughter, Hawking realized he could apply some of the work he had done with causal theory to black holes. He also had

David J. Eicher *is editor of* Astronomy *and is proud to be a member of the Starmus Festival Board of Directors, as well as a lifelong admirer of Stephen Hawking.*

ALL ILLUSTRATIONS: *ASTRONOMY*: KELLIE JAEGER

1963

Hawking was diagnosed with a motor neuron disease that today is commonly known as ALS or Lou Gehrig's disease. By the end of the decade, he was forced into a wheelchair. AIP EMILIO SEGRÈ VISUAL ARCHIVES, *PHYSICS TODAY* COLLECTION

1988

Hawking, along with his co-author Roger Penrose, received the Wolf Prize in Physics for his work on black holes. Such an honor is often considered second only to a Nobel Prize. AIP EMILIO SEGRÈ VISUAL ARCHIVES, WOLF FOUNDATION

1998

Hawking visited President Bill Clinton in the White House Oval Office on March 5 prior to giving the second White House Millennium Evening Lecture, a series celebrating human advancement in science and the arts. WHITE HOUSE PHOTOGRAPH, COURTESY AIP EMILIO SEGRÈ VISUAL ARCHIVES, *PHYSICS TODAY* COLLECTION

published significant work on the meaning of general relativity, showing among other things that it would break down at singularities, i.e. in black holes.

General relativity and black holes

Hawking next turned to attempting to combine general relativity, the behavior of the very large, with quantum theory, the behavior of the very small. He used black holes as the theoretical test bed for quantum behavior. How would quantum fields scatter off of a black hole? His calculations demonstrated, much to his astonishment, that a black hole would show some emission, not simply scattering.

This finding showed that a previously unknown relationship must exist between thermodynamics — the science of heat — and gravity. Hawking had discovered that over time radiation leaks away from a black hole, eventually evaporating it. This came to be known as Hawking radiation.

Hawking's calculations showed that the radiation leaking from black holes would be thermal and random. But the evaporating black hole left a paradox at the heart of physics. How could the radiation left over carry all the information about what made the black hole? And if the information was lost, that would seem to be incompatible with quantum physics. Hawking believes that information is not lost, but it is simply not returned in a meaningful way.

In the early 1970s, Hawking spent time doing research with his good friend Kip Thorne at the California Institute of Technology, and the Hawking family enjoyed the Golden State. He graduated from a mechanical to an electric wheelchair, and taking care of him became a family affair. Back to England in the mid-'70s, the Hawkings continued to focus on their many family activities as Stephen's condition gradually worsened.

Complexity and challenge

By the 1980s, the Hawkings' marriage had become strained, and Jane began to have romantic feelings for a church organist she knew, Jonathan Hellyer Jones. He moved in with the family to help take care of Hawking, who did not object, thinking the family would need someone to care for them when he was gone. Hawking began to have choking fits, and during a Swiss trip in 1985, was rushed to the hospital and placed on a ventilator. Surgeons had to perform a tracheotomy, meaning Hawking's ability to speak, already badly degraded, would now be completely gone.

Now Hawking could only communicate by learning to spell out words one letter at a time on a spelling card using eyebrow motions to indicate choices. It was, needless to say, exceptionally frustrating at first and required countless hours of practice.

One of the greatest minds the world has known was in danger of being completely cut off from the rest of us, still functioning magnificently, but in danger of no clear channel of communication.

Moreover, Hawking had become upset with the increasing closeness of Jane and Jonathan. He moved out, into a flat, in 1990. One of his nurses, Elaine Mason, who he had grown close to over hours of caregiving, moved in with him. Five years later they were married, and Hawking declared: "It's wonderful — I have married the woman I love." He has subsequently stated that several times, Elaine has saved his life.

In 1982, Hawking had the idea to write a popular level book about his research on the universe, and the subsequent title, *A Brief History of Time*, was an incredible runaway best-seller. Rather than his technical publisher, Cambridge University Press, Hawking sold the book to Bantam, wanting to reach as large a market as he could.

Following the huge success of his book, Hawking turned to another spectacular

2005

Queen Elizabeth II of Britain visited Hawking at the Centre of Mathematical Sciences at Cambridge University in May when he was the Lucasian Professor of Mathematics. NIGEL LUCKHURST

2005

Despite increasing disability, Hawking has spent much of the past two decades focusing on his research and bringing cosmology and astrophysics to a wider audience with various books that extend from his original 1988 best-seller, *A Brief History of Time* (Bantam Books). PHILIP WATERSON, LBIPP, LRPS

2006

Hawking received the Copley Medal from Britain's Royal Society for his theoretical work. Then NASA Administrator Michael Griffin (far right) helped present the medal, which had flown to the International Space Station aboard the space shuttle *Discovery*, with Martin Rees (center), then president of the Royal Society. THE ROYAL SOCIETY

subject in physics, the possibility of time travel. In 1990, Hawking's friend Thorne had posited that perhaps time travel would be possible by passing through wormholes (black holes that could be used as ways to travel in time or space). Can the laws of physics allow a wormhole and space-time to be so warped that a spaceship could enter it and return to its own past? Could an advanced civilization construct a time machine by modifying a small part of space-time so that it closed time-like curves of space in a finite region?

Theoretically, the answer depends on the model you use and also the assumptions you make about various conditions within it. But, to quote Hawking, "the future looks black for time travel, or should I say blindingly white?" It does not appear that the laws of physics allow for traveling back in time, regardless of the space-time curvature. "Even if some different theory is discovered in the future," says Hawking, "I don't think time travel will be possible."

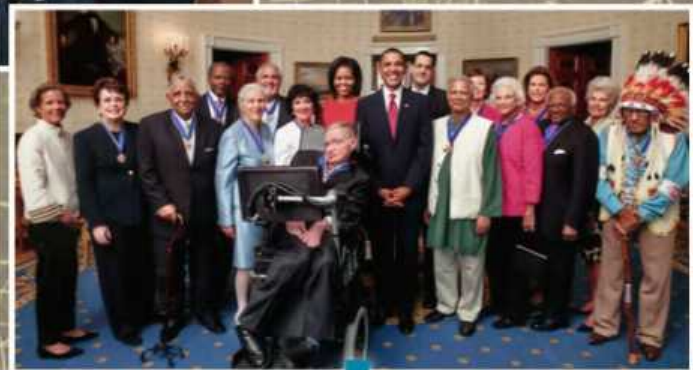
Over time, Hawking has come to live with his disability with increasing success. He has moved to a more sophisticated wheelchair and to progressively better systems of computer communication. His accomplishments in theoretical physics, cosmology, astrophysics, and related fields have formed a new basis for understanding relativity and the origin and fate of the cosmos, a century after the heyday of Einstein.

One could rightly ask the question: How is it that Stephen Hawking has not been awarded a Nobel Prize?

Hawking's mind is of course as sharp as ever. This was witnessed most recently by astronomy enthusiasts from his two gripping talks at Starmus.

2013

Hawking visited the Large Hadron Collider, where the Higgs boson was discovered, an "exciting development" in cosmology, according to the renowned physicist. COURTESY CERN



2007

Hawking experienced weightlessness in April as part of a Zero Gravity Corporation flight that raised $144,000 for charity. ZERO-G

2008

Hawking visited students attending the African Institute for Mathematical Sciences, located in South Africa, in May as part of the Next Einstein Initiative to support those interested in science and technology. JUDITH CROASDELL

2009

Hawking returned to the White House Oval Office as one of the 16 recipients of that year's Presidential Medal of Freedom. THE WHITE HOUSE

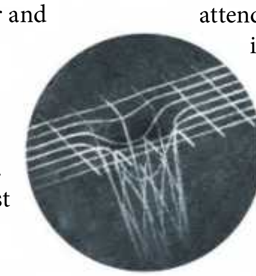
Starmus 3: A Tribute to Stephen Hawking

Hawking's presence at Starmus 2, in September 2014 in the Canary Islands, sets up an amazing next iteration of the world's greatest science festival. For those not familiar with Starmus, the gathering was founded by astronomer Garik Israelian and features a board of directors including astrophysicist and Queen guitarist Brian May, cosmonaut Alexei Leonov, evolutionary biologist Richard Dawkins, musician Peter Gabriel, and Hawking himself.

The first Starmus took place in 2011, the second last year, and the third and greatest thus far is planned for June 27–July 2, 2016. Nearly 1,000 people attended Starmus 2 in Tenerife and La Palma, enjoying stellar talks from a who's who of scientists, astronaut-explorers, and artists.

Starmus 3 will be far bigger yet, with the theme constituting a tribute to Hawking and his life in science. The event, which is expected to draw on the order of 1,800 people, will be titled: "Beyond the Horizon: Tribute to Stephen Hawking."

Nothing like Starmus 3 has ever taken place before. Ten Nobel Prize-winning scientists will be delivering talks, including astrophysicists Adam Riess and Brian Schmidt (co-discoverers of dark energy); astrophysicist Robert Wilson (co-discoverer of the cosmic microwave background radiation); chemists Harry Kroto (discoverer of buckminsterfullerene) and Eric Betzig (fluorescence microscopy); physicist David Gross (particle physics); biologists Carol Greider and Elizabeth Blackburn (DNA enzymes); and Edvard Moser and May-Britt Moser (brain cell physiology).



Moreover, incredible astronauts and astronomers also will speak at the festival. They include Leonov, the first human to walk in space; Apollo astronaut Rusty Schweickart; cosmonaut Sergey Volkov; astronauts Chris Hadfield, Garrett Reisman, and Michael López-Alegría; and astronomers Lord Martin Rees, Kip Thorne, Jill Tarter, Robert Williams, Neil deGrasse Tyson, and Neil Turok. Other big-name speakers will be announced soon.

The festival also will include time spent at the 10.4-meter Gran Telescopio Canarias, the world's largest optical telescope, not to mention observing under some of the best skies on Earth. Plus, attendees won't want to miss the Sonic Universe Concert featuring Brian May and other special guests.

Says Hawking: "With this next edition, Starmus confirms its position as a unique debating chamber for the future of the human race." It is an event filled with intellectual exploration, amazing astronomy, music, and fun, and is structured so that attendees can spend time with these leading lights of science. This is what makes the festival unique. For more details on Starmus, see www.starmus.com.

Hawking's life, to be celebrated in a special way next year, casts an enormous example onto the world for those of us who adore the universe. He has shown, time and again, that the power of the human mind has a unique ability — to outstretch troubles and challenges in our everyday world, to aspire to and to reach a greater understanding of ourselves on Earth.

That's why all humans owe something to Hawking. He has been not only one of the brightest minds we have ever seen, but also a shining example of the best ideals of humanity. Let the celebration begin.

TO SEE MORE RECENT PHOTOS OF STEPHEN HAWKING, VISIT **www.Astronomy.com/toc.**

HOLIDAY GIFT-

If astronomy is on your gifting list, here's how to please without breaking the bank. **by Phil Harrington**

With the holidays upon us, there's no better gift to give to a budding stargazer than a telescope or accessory. With it, they can soar above the stark surface of the Moon, travel to the other worlds in our solar system, or plunge into the dark void of deep space to survey clusters of jewel-like stars, huge interstellar clouds, and remote galaxies. Whether the recipient is young or old, your gesture of generosity will be putting them on a lifelong path of discovery.

But which telescope is right for them? That's a difficult question to answer because it is a personal choice. Much also, of course, depends on your budget. With that in mind, you can purchase all of the telescopes described below for less than $500, with several under $200. They each come complete with a mount, finder, and at least one 1¼" eyepiece.

All telescope designs have their pros and cons. Refractors are always popular picks, especially for those who enjoy viewing the Moon and planets. Reflectors are often the telescopes of choice because they offer more aperture per dollar than other designs. But catadioptric telescopes (whose optics include both lenses and mirrors) have a strong legion of owners who value the compact design and ease of transport.

Refractors

Celestron offers several refractors in the 2.8- to 4-inch aperture range that would make wonderful gifts. On the low end of the price scale, the 1 **AstroMaster 70AZ Telescope** ($149.95) combines a 2.8-inch f/13 achromatic tube assembly with a simple but sturdy altitude-azimuth mount. Not a lot of frills; just a good, basic telescope that's light enough for an elementary school-age child to carry.

For a larger refractor, Celestron's 2 **Omni XLT 102 Telescope** ($499.95) is a nice option. Although it's at the top end of our price range, the XLT102 marries a 4-inch f/9.8 telescope to the company's time-tested CG-4 German equatorial mount to create a nice instrument for observing as well as for dabbling with lunar photography.

Orion's venerable 3.1-inch f/5 3 **ShortTube 80 Equatorial Refractor Telescope** ($299.99) must be on your list if you're looking for a great little grab-and-go scope. Because it was first introduced more

1

2

3

7

8

9

GIVER'S GUIDE

ROBERT POSTMA

than two decades ago, the ST80 has been a favorite among budget-conscious amateurs who enjoy wide-field views of Milky Way star clouds. You can buy the ST80 in several configurations with or without a mount.

Vixen's **4 Space Eye 70 Telescope** ($139.95) weighs less than 7 pounds (3.2 kilograms) and makes a great gift for a child. For a really low price, you get Vixen's famous optical quality, a nicely designed mount and tripod, and two eyepieces.

Many amateurs these days like their telescopes to do the finding and tracking. For them, iOptron's **5 SmartStar–R80 Computer Telescope with GPS** ($370) makes a great choice. This little 3.5-inch f/5 refractor comes on iOptron's computerized Cube alt-azimuth mount that includes a tracking system as well as a database of 50,000 celestial objects. The scope is available in blue and pink.

Reflectors

Several affordable alternatives populate this category. The smallest scope here is an ideal design for the youngest budding astronomers. Celestron's 3-inch f/4 **6 COSMOS FirstScope** ($69.95) comes with a tabletop base that makes setup a breeze. Total weight is just over 4 pounds (1.8kg). Inspired by the 2014 television series Cosmos: A SpaceTime Odyssey, the FirstScope's tube features a colorful image of the Helix Nebula (NGC 7293).

Looking for a little more aperture? Orion's **7 StarBlast 4.5 Equatorial Reflector Telescope** ($199.99) is a great alternative. While perfect as a kid's scope, in truth anyone who enjoys panning the Milky Way or viewing targets like the Pleiades (M45) and the Andromeda Galaxy (M31) will love this 4½-inch scope. The mounted StarBlast is only 25 inches (63.5 centimeters) tall and weighs just 13 pounds (5.9kg).

Astronomers Without Borders' 5.3-inch f/4.8 **8 OneSky Telescope** ($199.99) is also a great starter telescope for a child of any age. No bells, no whistles, and no gimmicks; just good optics in an easy-to-setup-and-use package. Place the scope on a picnic table, extend the collapsible tube, and the one-armed alt-azimuth-mounted scope is ready to explore the sky.

Phil Harrington *is a contributing editor of* Astronomy *and a longtime equipment guru.*

4

5

6

10

11

12

13

14

15

19

20

21

The three previous telescopes are great for low-power wide-field viewing. But if your gift recipient longs for close-up views of the Moon and planets, then it is tough to beat a more traditional 6-inch f/8 or 8-inch f/6 reflector.

Fortunately, many alternatives make the perfect gift. Orion's 9 **SkyQuest XT6 Classic Dobsonian Telescope** ($309.99), as well as the XT8 model ($389.99), immediately comes to mind. The company outfits both with a basic Dobsonian-style mount that is easy to assemble and even easier to use.

More technologically advanced versions are also available that marry the scope to digital aiming devices and even full go-to computer control. While these are popular options, they raise the price a few hundred dollars beyond our $500 cap.

Zhumell also imports several no-frills Dobsonian-style reflectors that are well within our budget. Its 10 **Z8 Deluxe Dobsonian Reflector Telescope** ($399) includes a Dob-style base as well as a finder and eyepieces for less than $400. The total package tilts the scale at 54 pounds (24.5kg), but you can separate the tube and mount for travel and setup.

The Orion and Zhumell scopes all have solid tubes, which can sometimes be difficult to transport to dark skies. For astronomy on the go, Sky-Watcher USA's 11 **Collapsible Dobsonian 8"** ($449) offers a great solution. Here, the solid tube is replaced by a four-pole truss support system. To transport the telescope, slide the focuser end down the poles and lock it to the mirror's lower-tube assembly. To set it back up, slide the upper assembly up the poles and lock it in place.

Catadioptrics

Finally, let's look at some catadioptric instruments. Cats are great do-it-all scopes. They combine a compact size with a large enough aperture to see many sights. While most are above our $500 cap, there are a few noteworthy exceptions.

One that immediately comes to mind is Vixen's 12 **VMC95L 3.7" Reflector Telescope** ($339). A meniscus lens in the front helps bring light striking the primary mirror to a focus. The VMC95L features a built-in 1¼" diagonal and straight-through camera port. The full package also includes the company's Mini Porta alt-azimuth mount, one eyepiece, and a red-dot finder.

Another Cat that just squeezes under the price cap is Celestron's 4-inch f/13 13 **NexStar 4SE Computerized Telescope** ($499). This Maksutov-Cassegrain optical tube has a computerized brain that incorporates Celestron's SkyAlign GoTo system. Once time, date, and location are entered into the onboard computer, the user only has to aim the telescope at three bright stars. No need to tell the computer which star is which; it automatically calculates that. After the telescope mount initializes, use the hand controller to find any of the objects listed in the onboard database.

Eyepieces and filters

Your gift recipient already has a telescope? If so, no one can have too many eyepieces! It's best to have a set that offers a variety of magnifications.

Low power is best for large deep-sky objects, medium power is perfect for lunar sightseeing as well as for viewing smaller deep-sky targets, and high power works well for subtle planetary detail or to split close double stars.

More than three decades ago, my wife gifted me with some Tele Vue Plössl eyepieces, and the universe hasn't looked the same since. Ranging in focal length from 8mm to 55mm, Tele Vue's 14 **Plössl Eyepieces** ($95 to $240) set the standard against which all others are judged.

If your budget is a little more limited, Orion's 15 **Sirius Plössl Telescope Eyepieces** ($47.99 to $54.99) are worth a look. They offer focal lengths from 6.3mm to 32mm. Many observers enjoy "super" eyepieces with apparent fields of view nearly double that of conventional designs.

The panoramic views often come paired with long eye relief for more comfortable viewing. These can be big-ticket items, costing many hundreds of dollars for just

one eyepiece. No doubt, though, the views are spectacular.

Several less expensive alternatives are available and worth considering. Celestron's 16 **X-Cel LX Eyepieces** ($79.95 each) range in focal length from 2.3mm to 25mm. Each has a 60° apparent field of view and 16mm of eye relief.

Celestron's new 17 **Ultima Duo Eyepieces** ($129.95 each) have 68° apparent fields for panoramic views. And with 20mm of eye relief, those views are comfortable, even if astigmatism forces the observer to wear their eyeglasses. Six focal lengths range from 5mm to 21mm. And if your astronomer enjoys photography, each eyepiece also has a built-in T-adapter for coupling a camera.

If the target of your gifting already has a good selection of eyepieces, consider a high-quality Barlow lens. A Barlow effectively doubles the number of eyepieces in a person's collection. But don't scrimp. You get what you pay for. Tele Vue's 18 **2x Barlow 1¼"** ($120), Celestron's 19 **X-Cel LX 1.25" 3x Barlow Lens** ($89.95), and Orion's 20 **High-Power 1.25" 2x 4-Element Barlow Lens** ($129.99) are some of the best. All are available in a choice of 1¼" and 2" formats.

To take the guesswork out of selecting eyepieces and Barlows, both Orion and Celestron sell well-designed accessory kits. Orion's 21 **1.25" Premium Telescope Accessory Kit** ($179.99) comes with five Plössl eyepieces (6.3mm to 40mm), six color filters, a Moon filter, and a 2x Barlow lens. Celestron's 22 **1.25" Eyepiece and Filter Kit** ($128) contains five Plössls, a 2x Barlow lens, six color filters, and a Moon filter. Both also include foam-lined carrying cases.

Another good gift option is a filter or set of filters. These accessories come in two types. Color filters help enhance contrast of subtle planetary features, making them popular accessories. For those just starting out, choose basic colors, such as deep yellow (also known as #15), orange (#21), red (#23), green (#58), and blue (#80A).

If city lights spoil your astronomer's views, then the second variety of filter, a light-pollution reduction (LPR) filter, would make a nice gift. Manufacturers offer several types of LPR filters, but a narrowband ("nebula") filter is probably best for a budding astronomer. These muffle all wavelengths except those narrow portions associated with ionized hydrogen and doubly ionized oxygen, common to emission and planetary nebulae. Some of the most popular narrowband filters sold today include DGM Optics' 23 **Narrow Pass Band** ($75 for the 1¼"; $150 for the 2"), Thousand Oaks' 24 **LP–2 Narrowband** ($89 for the 1¼"; $179 for the 2"), Orion's 25 **1.25" UltraBlock NarrowBand Filter** ($105.05), and Tele Vue's 26 **Bandmate OIII Filter** ($100).

The sky's the limit when it comes to gifts for the amateur astronomer. Whatever you choose, you'll be adding hours of enjoyment for the lucky recipient. Just be sure that, afterwards, they share the fun with you, too.

Tales of the Astronomers Royal

Personal feuds, world wars, and revolutionary science are all part of the history of this British post.

by Raymond Shubinski

A few years ago, I had dinner with John Campbell Brown, Astronomer Royal for Scotland. Yes, Scotland and England both have Astronomers Royal. Ireland also had one until 1921, when the post was abolished due to Irish independence.

The Astronomer Royal and I shared a meal at Billy Ray's Diner in Prestonsburg, Kentucky. As I munched on fried okra, I asked Brown if he made a good living as the Astronomer Royal. After a dramatic pause and a good laugh, he said that overall it costs more for the privilege than he receives in salary. In fact, Brown said he makes all of £100 a year (about $160) with the appointment. "I'm not in it for the money."

This unlikely encounter with the Astronomer Royal for Scotland in Kentucky set me on a quest to find out more about the woefully underpaid appointment and the men who have held the title. I discovered stories of ambition, achievement, small-mindedness, and even scandal.

In the present day, Greenwich Observatory's busy site is put to better use as a museum. DAVID J. EICHER

John Flamsteed was the first Astronomer Royal and first man to run the Royal Observatory Greenwich, but he also made enemies for himself. COURTESY OF THE SMITHSONIAN LIBRARIES, WASHINGTON, D.C.

A legacy begins

A royal warrant established the position of English Astronomer Royal in March 1675. The noted astronomer and all-round curmudgeon, John Flamsteed, accepted the honor and became the first of 15 Astronomers Royal to date. A second warrant in June of that year ordered an observatory built in Greenwich Park, with Flamsteed its first director. This seemed like a marriage made in, well, heaven. But as with so many romance stories, the happy couple soon hit some rough spots.

Flamsteed was granted the same figure of £100 a year (a much more lucrative $13,500 in today's money) to administer and operate the observatory. King Charles II was always short of money, so the building was constructed from used bricks with funds raised in part by the sale of wet gunpowder. Despite this impecunious beginning, Flamsteed soon commissioned telescopes and clocks to use in an ambitious observing project.

It wasn't long before Flamsteed fell out with fellow observers and scientists Isaac

Raymond Shubinski *is an* Astronomy *contributing editor. An experienced observer, he also enjoys astronomical history.*

Newton and Edmond Halley over the use of his ever-growing set of observations. Flamsteed was unwilling to release what he considered an incomplete data set, while Newton and Halley felt their own work — and that of the astronomy community as a whole — could be improved by Flamsteed's hoarded and highly precise measurements. They repeatedly accessed Flamsteed's observations without his permission.

The battle escalated years later when a frustrated Newton and Halley published a catalog of Flamsteed's star positions against his wishes. The Astronomer Royal had his revenge by burning 300 of the 400 printed copies. After his death, Flamsteed's wife finally published the corrected and expanded catalog, and Halley used the work to support an even grander project. For the 22 years he served as the second Astronomer Royal, Halley labored on a project that would help guarantee Britain's supremacy at sea.

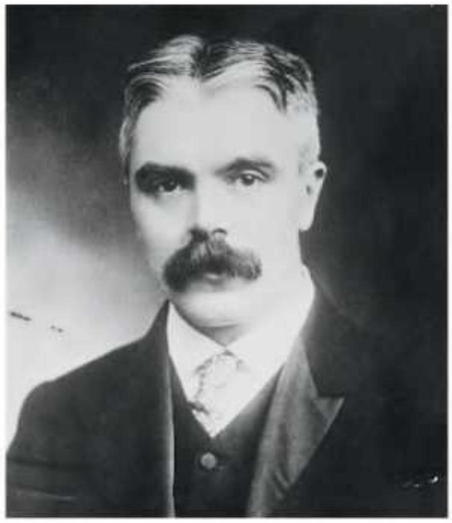
Saving lives with star charts

In October 1707, a British fleet of 22 ships entered the English Channel on their way home. Bad weather and bad charts put them off course, resulting in a massive disaster that cost a staggering 1,647 lives. Halley took his post in 1720 and began the monumental task of providing sailors with a method to determine longitude at sea and thereby — hopefully — avoid future disasters. He sought to create a catalog that would provide celestial positions to an unprecedented accuracy and concentrated on the motion of the Moon among the stars near the ecliptic, the Sun's apparent yearly path through the skies.

In the early 18th century, there were no clocks robust enough to survive a sea voyage while keeping accurate time. Halley and others realized the Moon could serve as a celestial clock. All a seaman had to do was measure the angular separation between the Moon and a nearby star and note the local time. He could then compare

NATIONAL MARITIME MUSEUM, GREENWICH, LONDON, AIRY COLLECTION

The seventh Astronomer Royal, George Biddell Airy, established the prime meridian in Greenwich in 1851, setting the standard for timekeeping still used today.



As the ninth Astronomer Royal, Frank W. Dyson oversaw Arthur Eddington's eclipse expedition of 1919 that sought to prove Albert Einstein's theories of relativity. LIBRARY OF CONGRESS

his observations to an almanac with the same information, set for the longitude of Greenwich Observatory. Do the math, and, voilà, he knew the difference in time between his position and Greenwich, and therefore his longitude. Simple, right?

Over a 20-year period, Halley made thousands of observations of the Moon, as he struggled to prove this lunar method of determining longitude feasible. His observations were riddled with errors, however, and it fell to others to make corrections that provided the fifth Astronomer Royal, Nevil Maskelyne, with the data needed to actually perform the calculations.

Maskelyne, like those before him, struggled with the longitude problem for the 46 years of his tenure as Astronomer Royal. A strong proponent of the lunar method for determining longitude, Maskelyne pushed for an almanac of data to be published annually. *The Nautical Almanac and Astronomical Ephemeris* was published in 1767 due to his efforts. Maskelyne also was a member of the Longitude Board, a group appointed by Parliament and tasked with awarding substantial prize money to whoever could conquer the problem of determining longitude.

In the end, a watchmaker by the name of John Harrison solved the longitude question by inventing a clock that could keep accurate time even on the rolling ocean. The Longitude Board, disorganized and distracted by competing interests and changing rules, did not see fit to award Harrison, or indeed anyone, the full prize.

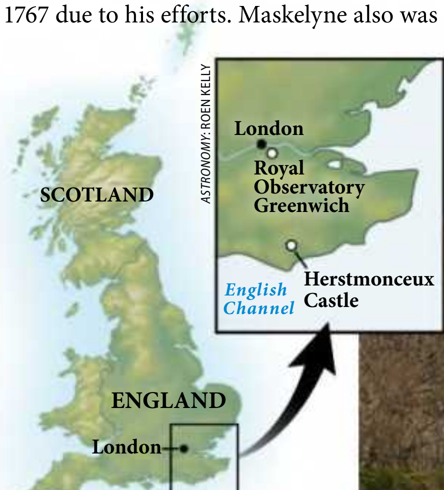
From the stars to Earth

Longitude was not Maskelyne's only interest. In 1774, he spent time in Scotland measuring the tug of the mountain Schiehallion on a plumb, or weighted, line. He was trying to measure Earth's density and hence its gravitational force. By measuring tiny deviations of the plumb line from true perpendicular, Maskelyne could calculate the gravitational pull of the mountain and extrapolate Earth's overall density. Amazingly, he came up with measurements that vary by only about 20 percent from the current value. Not bad for a plumb line and some, as Maskelyne called them, "very long and tedious" calculations.

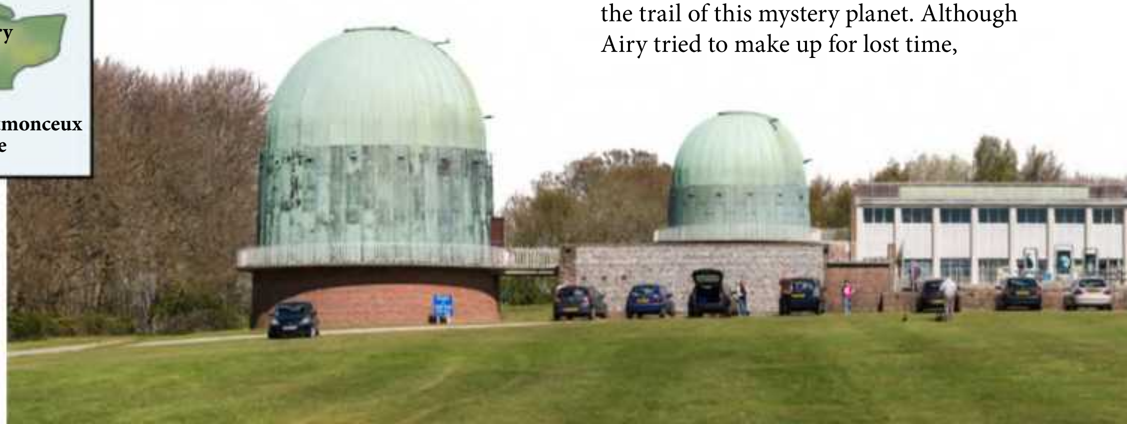
The seventh Astronomer Royal, Sir George Biddell Airy, succeeded to the post in 1835, two years before Victoria ascended the throne of Great Britain. Like Maskelyne, he served in this capacity for 46 years. Also like his predecessor, Airy was interested in Earth's gravity. In 1854, after several failed attempts, he succeeded in calculating our planet's mean density. He did this by descending more than a thousand feet into a mine, armed with pendulums. Airy knew the exact period of the swinging pendulums on Earth's surface. Deep underground, he measured minute variations in the pendulums' swings. This allowed Airy to arrive at an even more accurate value of Earth's density.

Airy completely overhauled Greenwich Observatory, removing old equipment and installing state-of-the-art replacements. Under his guidance, Greenwich became synonymous with precision and accuracy. Airy remeasured the great meridian at Greenwich in 1851, establishing a new prime meridian, which ran through the transit circle he had installed as part of his renovations. In 1884, Greenwich was recognized as *the* prime meridian of the world, making Greenwich Mean Time (GMT) the official starting point for all time measurements east and west. The French, always the rivals of the English, refused to accept this designation for more than 25 years.

It was another Anglo-French rivalry, however, that sparked the now infamous Neptune scandal. A young Cambridge mathematician named John Couch Adams spent the summer of 1845 working on the problem of Uranus and why it did not always appear at its predicted location. Adams suspected that a massive planet beyond Uranus was the culprit. Through a complicated string of miscommunications and misunderstandings, Airy paid little attention to Adams and his calculations. In July 1846, Airy realized the French mathematician Urbain Le Verrier was also on the trail of this mystery planet. Although Airy tried to make up for lost time,



ASTRONOMY: ROEN KELLY



Neptune was discovered September 24 of that year using Le Verrier's calculations. Airy had lost an opportunity for English preeminence. This mistake on Airy's part is a point of criticism and debate even now, over a century and a half later.

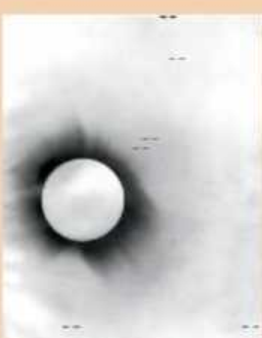
The Royal Observatory Greenwich (seen here as it was in 1824) served as the seat of the Astronomer Royal for almost three centuries. WELLCOME LIBRARY, LONDON

Proving relativity

Airy defined precision and innovation in astronomy for the bulk of the 19th century, but other men left marks in their own time. Since Airy stepped down in 1881, eight more Astronomers Royal have taken their turn. Frank W. Dyson had the distinction of being Astronomer Royal twice. In 1905, he was appointed Astronomer Royal for Scotland. Five years later, he became the ninth English Astronomer Royal, turning the Scottish position over to Ralph A. Sampson.

Dyson is best known for encouraging and organizing the eclipse expeditions of 1919 to verify Albert Einstein's theory of general relativity. Like others at Greenwich, Dyson was interested in time, and Einstein's theories challenged the concept of absolute time. His ideas intrigued astronomers and physicists alike. The problem was how to verify these theories.

Dyson proposed taking photographs of the Sun and stars close to it during the total solar eclipse in May 1919. If Einstein was right, the positions of the observed stars would be displaced slightly due to the Sun's gravity. The English astronomer Arthur Eddington took up the challenge and made his observations from the island of Príncipe near the coast of West Africa. He successfully measured the predicted shift, validating both Einstein and relativity. In a very real sense, Dyson and Eddington were responsible for making Einstein famous.



This photographic plate shows the Sun during the 1919 eclipse, with the locations of stars marked. If Albert Einstein's theories were correct, then stars would appear offset from their true and calculable locations, as the Sun's gravity bent their light. These measurements, taken by Arthur Eddington, proved exactly that. ROYAL ASTRONOMICAL SOCIETY

War comes to the observatory

Harold Spencer Jones became the 10th Astronomer Royal in 1933 and witnessed the bombing of Greenwich Observatory during World War II. The damage was not serious, but the subsequent growth of London after the war did what the Luftwaffe could not — drove the astronomers from their hilltop in Greenwich Park.

Spencer Jones had been concerned about conditions in the early 1930s and recommended a move then. When the war began, this move was officially put on hold, but Spencer Jones decided to shift much of the observatory's equipment out of London anyway, rightfully fearing damage. After the war, encroaching light pollution and worsening smog forced a permanent relocation. In 1948, the Astronomer Royal took up residence at Herstmonceux Castle. The castle served as the official offices of both the Astronomer Royal and Greenwich Observatory from 1957 until 1988.

The modern age

Today, the appointment of Astronomer Royal has shifted from hands-on astronomy to an honorary position. Current Astronomer Royal Martin Rees, Lord Rees of Ludlow, is a cosmologist, author, and advocate for social and environmental change. He lectures and writes about science and society in an effort to save humanity. This is a far cry from the work done by the likes of Halley and Airy. The position of Astronomer Royal has evolved over the years but is still part of the astronomical fabric of England. And even though there are no longer any special duties for the Astronomer Royal, I'm sure he still looks forward to his £100 stipend each year.

After World War II, the Royal Observatory relocated to Herstmonceux Castle in an effort to avoid both light and air pollution from a rapidly growing London. DAVID ILIFF (LICENSE: CC-BY-SA 3.0)

COSMICIMAGING
BY ADAM BLOCK

High dynamic range imagery

In 1954, Charles Wyckoff had a problem. He needed to freeze atomic bomb explosions on film. The initial flash of light, however, would fog the exposure, which prevented the recording of anything else.

His solution was to combine images using high-speed cameras with film emulsions of differing sensitivities. He also delayed the initial exposure by a fraction of a second. This allowed him to capture the emerging brilliant fireball as well as the surrounding scene.

Many photography historians point to his work as the birth of high dynamic range (HDR) imaging. Although our celestial scenes rarely require millisecond exposures, a similar problem often arises when we render our astronomical quarry.

In order to show the faintest and brightest features of a scene, specialized algorithms compress the dynamic range of images by making the values of faint and bright elements similar. For a given input, properly exposed portions of an image will not change. This processing, however, will dim overly bright areas to create contrast for features found there. The nature of the algorithm (and its parameters) determines the look of the result. PixInsight offers an easy way to adjust HDR images by using a tool called "HDR Multiscale Transform" (HDRMT).

Examine Image #1 to see some of the parameters for this utility. Based on the information in my December column, we can make some good guesses about how HDRMT works. It deconstructs the image using a wavelet scaling function, and we can determine the number of layers it should probe. This tool uses a numbering scheme, so layer four will have features around eight pixels in size.

However, unlike a generalized wavelet transform, in HDRMT the layers correlate to one another so they enhance low-contrast features in bright objects. The "Median Transform" is a different algorithm that produces good results for more than six layers.

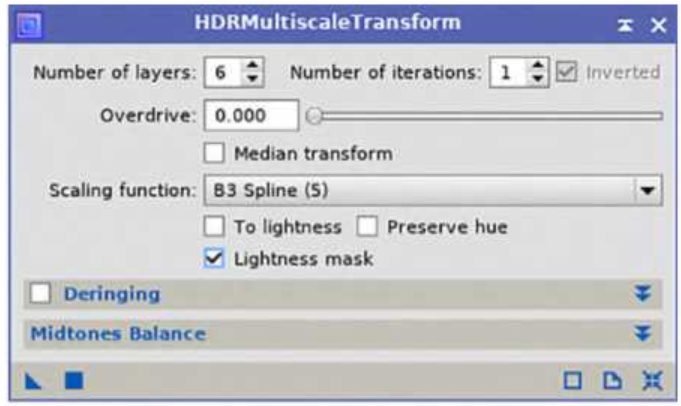


Image #1. This screen shot shows some of the options of PixInsight's HDRMT tool.
ALL IMAGES: ADAM BLOCK

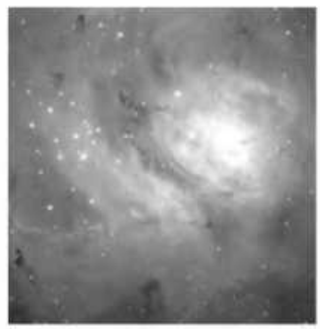


Image #2. The author aggressively brightened his luminance image to reveal faint details. Note that the brightest regions appear almost entirely white.

Image #3. After the author processed the luminance image in Image #2 with HDRMT, it looked like this.

PixInsight designed HDRMT for permanently stretched (nonlinear) images. What follows are settings I used on my luminance image of the Lagoon Nebula (Image #2). First brighten your image so that faint details are visible and bright regions are nearly blown out (completely white). Save this as a nonlinear image.

In PixInsight, put the "Screen Transfer Function" settings into the "Histogram Transformation" utility, and then apply it to the image. I used seven layers and the broad scaling function, called "B3 Spline (5)," which are good choices for working on large structures. I wanted to strongly affect the region around the hourglass part of the nebula.

One iteration is plenty, and I also checked the "Lightness Mask" option to process only the brightest features and to moderate the result (Image #3). This new image has two benefits. First, the overall brightness profile is grayer than before, which makes it easier to blend in color. Second, the dust clouds, bright gaseous knots, and other low-contrast features are much more visible. This kind of tool — that features previewing adjustments with various settings — is the way to determine what works best with your data.

Image #4. This image shows the final result of part of the field of view. The author's processing brought out great detail and color. You can find a full-resolution version of this image at http://skycenter.arizona.edu/gallery/Nebulae/M8_32in.

FROM OUR INBOX

Science needs science fiction

Did anyone else note the irony of David J. Eicher's September article, "Part-time believers not needed," (p. 9) where he decries those who blend science and science fiction in some of their thinking? You know, the very issue that boldly proclaimed on the cover, "Multiverses: Science or Science Fiction?" Currently, multiverses lie firmly in the realm of science fiction, yet many reputable scientists believe they could exist. That the math supports their existence is interesting but hardly proof, so why would *Astronomy* devote an entire story to a strictly science-fiction concept? Many devices existing today were born in the ideas of science fiction. To so callously toss aside those who may mix science and science fiction seems rather short-sighted — **John A. Ferko,** Davis-Monthan Air Force Base, Arizona

BROWSE THE "COSMIC IMAGING" ARCHIVE AND FIND VIDEO TUTORIALS AT **www.Astronomy.com/Block.**


TAKE THE UNIVERSE
with you
ASTRONOMY'S
DIGITAL EDITION lets you:
Link to website content, blogs, advertisers' websites, audio, and video.
Zoom in and magnify to see all the details of Astronomy's stunning images.
Take your issues with you wherever you go — and save on storage space!
ASTRONOMY.COM/DIGITALEDITIONS
Astronomy
500 COOLEST THINGS
ABOUT SPACE
Powered by Zinio™, digital editions are available on PC; Macintosh; Android™; iPad®; iPhone®; and Windows 8.
Zinio is a registered trademark of Zinio, LLC. Android is a trademark of Google Inc. iPad and iPhone are trademarks of Apple Inc.,
registered in the United States and other countries. Windows is a registered trademark of Microsoft Corporation in the United States and other countries.
P26036


Exclusive podcasts from Astronomy magazine
Superstars of Astronomy
Insights from science's greatest minds
Hear what the top names in astrophysics, planetary science, cosmology, and planetary defense have to say about the hottest topics in astronomy today
DEBRA FISCHER
All About Exoplanets
RUSTY SCHWEICKART
Asteroids and Astronauts
SETH SHOSTAK
The Hunt for E.T.
LISTEN NOW AT www.Astronomy.com/superstars
Astronomy magazine
Brought to you by CELESTRON
P25808

Attention, manufacturers: To submit a product for this page, email **mbakich@astronomy.com**.

Eclipse path maps

Great American Eclipse
Santa Fe, New Mexico

Great American Eclipse's state eclipse maps each measure 11 by 17 inches (28 by 43 centimeters) and contain information about the August 21, 2017, total solar eclipse. They track the extent of totality plus the center line and show the durations of totality in five-second increments on either side of it.

Price: $10
[e] greatamericaneclipse@gmail.com
[w] www.greatamericaneclipse.com

Laser pointer

HOTECH
Rancho Cucamonga, California

HOTECH's Astro Aimer G3 model combines a Class IIIa (less than 5 milliwatts) green laser, a red LED with three brightness modes, and an ultraviolet light. A ¼"–20 female thread allows you to mount the unit on a tripod.

Price: $119.95
[t] 909.987.8828
[w] www.hotechusa.com

Focusing rotator

Optec, Lowell, Michigan

Optec's Gemini combines a focuser and a camera rotator into a single package. The unit features 360° rotation with a resolution of 600 steps/degree. It is also capable of alt-azimuth de-rotation. The Gemini measures 2.5 inches (6.4cm) thick and has a 3.75-inch (9.5cm) aperture.

Price: $3,250
[t] 888.488.0381
[w] www.optecinc.com

Multipocket vest

SCOTTeVEST, Ketchum, Idaho

SCOTTeVEST's Q.U.E.S.T. Vest provides space for your observing and other essentials with 42 carefully engineered pockets. The vest is 65 percent cotton and 35 percent nylon. It has a zippered compartment for the built-in hood, has an attached eyeglass chamois, comes in beige or black, and is available in sizes S to XXXLT.

Price: $145
[t] 866.909.8378
[w] www.scottevest.com

SEE REPORTS ON 350+ PRODUCTS AT **www.Astronomy.com/equipment.**

COMING IN OUR NEXT ISSUE

Why we haven't found another Earth. Yet.

The search for alien Earths is heating up. But there's still no place like home.

Mercury: Land of mystery and enchantment

Scientists seek to understand the puzzling innermost planet

What happens when stars collide

PLUS

- Target 25 treats in Leo
- Sharing the sky above Las Vegas
- Stargazing in the city
- 11 top winter binocular treats
- We test Nikon's hot new astro camera

Astronomy magazine

NASA (EARTH); NASA/JHUAPL/CIW (MERCURY); ASTRONOMY: ROEN KELLY (STARS COLLIDE)

STATEMENT OF OWNERSHIP, MANAGEMENT, AND CIRCULATION

(Required by 39 USC 3685)

1. Publication title: ASTRONOMY
2. Publication No.: 531-350
3. Filing date: October 1, 2015
4. Issue frequency: Monthly
5. Number of issues published annually: 12
6. Annual subscription price: $42.95
7. Complete mailing address of known office of publication: 21027 Crossroads Circle, Waukesha, WI 53186
8. Complete mailing address of headquarters or general business office of publisher: Same
9. Publisher: Dan Lance, 21027 Crossroads Circle, Waukesha, WI 53186. Editor: David J. Eicher, same.
10. Owner: Kalmbach Publishing Co., 21027 Crossroads Circle, P.O. Box 1612, Waukesha, WI 53187-1612. Stockholders owning or holding 1 percent or more of total amount of stock are: Deborah H.D. Bercot, 22012 Indian Springs Trail, Amberson, PA 17210; Gerald & Patricia Boettcher Living Trust, 8041 Warren Avenue, Wauwatosa, WI 53213; Alexander & Sally Darragh, 1200 W. 3rd Street, Waterloo, IA 50701; Melanie J. Duval, 9705 Royston Court, Granite Bay, CA 95746; Harold Edmonson, 6021 N. Marmora Avenue, Chicago, IL 60646; Laura & Gregory Felzer, 714 N. Broadway, Milwaukee, WI 53202; Susan E. Fischer Trust, 3430 E. Sunrise Drive, Suite 200, Tucson, AZ 85718; Bruce H. Grunden, 255 Vista Del Lago Drive, Huffman, TX 77336; Linda H. Hanson, 363G Bateman Circle S., Barrington Hills, IL 60010; George F. Hirschmann Trusts, 363G Bateman Circle S., Barrington Hills, IL 60010; James & Carol Ingles, P.O. Box 2161, Waukesha, WI 53187; Charles & Lois Kalmbach, 7435 N. Braeburn Lane, Glendale, WI 53209; Kalmbach Profit Sharing/401K Savings Plan & Trust, P.O. Box 1612, Waukesha, WI 53187; James & Elizabeth King, 2505 E. Bradford Avenue, #1305, Milwaukee, WI 53211; Mahnke Family Trust, 4756 Marlborough Way, Carmichael, CA 95608; Milwaukee Art Museum, Inc., 700 N. Art Museum Drive, Milwaukee, WI 53202; Mundschau Family Trusts, 1530 Tallgrass Circle, Waukesha, WI 53188; Daniel & Mary Murphy, 10200 W. Bluemound Road, #333, Wauwatosa, WI 53226; Lois E. Stuart Trust, 1320 Pantops Cottage Court, #1, Charlottsville, VA 22911; David M. Thornburgh Trust, 8855 Collins Avenue, Apt. 3A, Surfside, FL 33154.
11. Known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages, or other securities: N/A
12. Tax status (for completion by nonprofit organizations authorized to mail at nonprofit rates): N/A
13. Publication title: ASTRONOMY
14. Issue date for circulation data below: September 2015

15. Extent and nature of circulation:	Average no. copies each issue during preceding 12 months	No. copies of single issue published nearest to filing date
a. Total number of copies (net press run)	138,068	135,928
b. Paid circulation (by mail and outside the mail)		
1. Mailed outside-county paid subscriptions	83,073	81,956
2. Mailed in-county paid subscriptions	-0-	-0-
3. Paid distribution outside the mails including sales through dealers and carriers, street vendors, counter sales, and other paid distribution outside USPS	13,633	11,493
4. Paid distribution by other classes of mail through the USPS	-0-	-0-
c. Total paid distribution [sum of 15b (1), (2), (3), and (4)]	96,705	93,449
d. Free or nominal rate distribution (by mail and outside the mail)		
1. Outside-county	-0-	-0-
2. In-county	-0-	-0-
3. Other classes mailed through the USPS	39	41
4. Outside the mail	217	-0-
e. Total free or nominal rate distribution [sum of 15d (1), (2), (3) and (4)]	255	41
f. Total distribution (sum of 15c and 15e)	96,961	93,490
g. Copies not distributed	41,107	42,438
h. Total (sum of 15f and g)	138,068	135,928
i. Percent paid (15c divided by 15f times 100)	99.74%	99.96%
16. Electronic copy circulation:		
a. Paid electronic copies	9,032	8,851
b. Total paid print copies (15c) plus paid electronic copies (16a)	105,737	102, 300
c. Total print distribution (15f) plus paid electronic copies (16a)	105,993	102,341
d. Percent paid, both print and electronic (16b divided by 16e times 100)	99.76%	99.96%

17. Publication of Statement of Ownership:
Publication required. Printed in the January 2016 issue of this publication.
18. I certify that all information furnished on this form is true and complete.
Nicole McGuire, Vice President Consumer Marketing. Date: September 29, 2015.

ASTRO**SKETCHING**

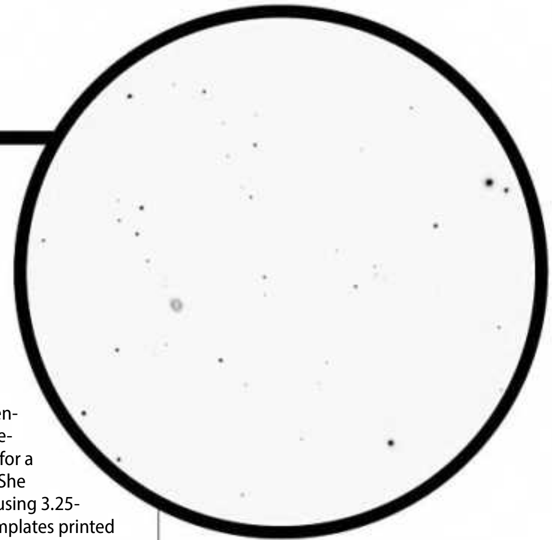
BY ERIKA RIX

Kneaded erasers

When comparing the versatility of erasers, the kneaded variety wins my vote every time. Among its attributes, two stand out above the rest — pliability and tackiness. It has the consistency of putty so that you can mold it to tackle even the smallest areas. And due to its absorbing nature, you can lift lightly applied graphite from the sketch without damaging the paper. This combination lets you perform the gradual fading and precise erasures that are key to creating detailed drawings. Let's talk about small areas first.

There's a striking 12th-magnitude planetary nebula, NGC 2022, nestled near the head of Orion the Hunter. You will be able to spot it at 100 power through small- to medium-sized instruments as a grayish 25" disk on an imaginary line from Lambda (λ) Orionis to Betelgeuse (Alpha [α] Orionis). Bumping the magnification to 275x reveals a defined ring structure with a hazy center. Larger scopes show a south-southwest to north-northeast elongation with brightened western and eastern edges. Simply for fun, see if you can spot a kite-like asterism flying just northeast of the disk.

While making my sketch, I found it necessary to remove excess graphite from within the ring in order to represent the gauzy center — remember that when using graphite on white paper for deep-sky objects, you're creating a negative sketch where starlight appears dark on a light background. After kneading the eraser to soften it, I molded it into a pointed tip. Then, with light pressure, I dabbed the tip inside the ring until I'd lifted sufficient graphite from that area to match the eyepiece view.



The author sketched NGC 2022 as seen through a 16-inch f/4.5 reflector on a non-tracking Dobsonian mount, using an Oxygen-III filter and a 13mm eyepiece with a 2x Barlow for a magnification of 281x. She sketched both targets using 3.25-inch diameter circle templates printed on white paper along with a black super-fine felt tipped pen for the brightest stars, a #2 pencil, a 0.5mm mechanical pencil, and a blending stump for nebulosity and stippling unresolved stars in the globular cluster. She used a kneaded eraser to define and shape the objects by removing excess graphite. The sketches have north at the top and west to the right. ALL SKETCHES/PHOTOS: ERIKA RIX

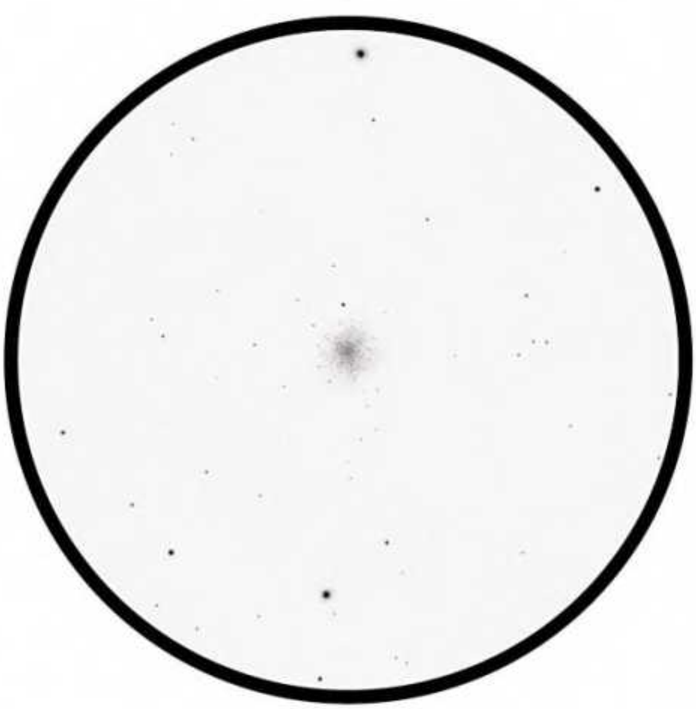
Simply fold the eraser into itself to refresh it as needed.

Next, I'll use M79 in Lepus to demonstrate a technique called subtractive drawing. I captured the distinct shape of this winter globular cluster by removing graphite from the paper with a kneaded eraser, as opposed to adding it with a blending stump.

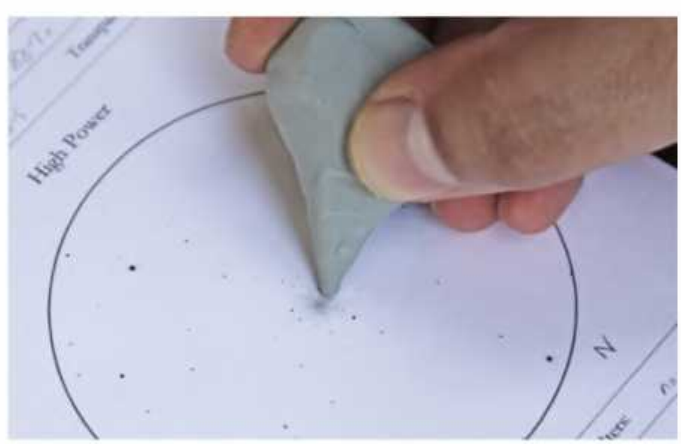
Nearly 4° south of Nihal (Beta [β] Leporis), this fuzzy 8.7'-wide cluster shines at magnitude 7.7 with a dense core, appearing comet-like through small telescopes. You may even resolve a few stars near its halo. Train a medium- to large-sized instrument on M79, though, and you can expect to pick out over 40 stars, along with a strand running along its eastern edge and another reaching 4' south.

Globular clusters rarely have an even shape when you observe them closely. I created a patch of dense graphite for the core of the cluster and used a blending stump to spread it outward for the halo. Once I added the stars, I molded the eraser to form a thin tip and then gently rubbed away the graphite to draw the cluster's distinct shape. Because I had plotted the stars with hard pencil pressure, the process left these smaller points intact.

When it comes to kneaded erasers' value for astronomical sketching, the two examples I've provided only scratch the surface. I'll leave it to you to explore it further during your own nights under the stars.



The author captured this view of M79 with a 6-inch Ritchey-Chrétien telescope on a German equatorial mount, using an 8mm eyepiece for a magnification of 171x.



The author molded the kneaded eraser she used for M79 to precisely erase areas of the globular cluster, form its unique shape, and lift graphite to achieve tone nuances.

BY KARRI FERRON

REGISTER TODAY! Go to www.Astronomy.com/register for access to bonus articles, photos, videos, and more.

Trips & Tours

America's Total Solar Eclipse

Drama is coming to the United States. On August 21, 2017, Sun-watchers along a line from Oregon to South Carolina will experience nature's grandest spectacle: a total solar eclipse. It's the first time darkness appears at midday for American observers in 26 years, so it's likely to be the most viewed sky event in history. That means the time to start planning for it is now.

Astronomy is here to make your 2017 total solar eclipse experience like no other. Thanks to our partnership with TravelQuest International, a top-rated travel company dedicated to astronomy-themed trips, we're inviting you on exclusive tours that celebrate the many cultural treasures America has to offer while we witness this celestial treasure above. Surrounding the August 21 total solar eclipse, you can: enjoy jazz, blues, country, and rock 'n' roll in New Orleans, Nashville, and Memphis; experience the spectacular scenery of the Pacific Coast from Seattle to San Francisco; or journey through the pristine forests and snowcapped mountains of the West's National Parks. Learn more about each option and book your American total solar eclipse trip today at **www.Astronomy.com/eclipsetours.**

OBSERVING TOOLS

Astronomy's "Sky Guide 2016"

Subscribers can start planning for important 2016 observing events with exclusive access to a PDF version of *Astronomy*'s "Sky Guide 2016." In 16 pages, Senior Editor Richard Talcott and Contributing Editor Martin Ratcliffe provide a month-by-month synopsis of planet visibility, Moon phases, meteor shower predictions, and more. Learn about the year's most exciting phenomena, from Mecury transiting the Sun to a bright Mars showing. You'll return to this guide again and again throughout 2016. Download it now at **www.Astronomy.com/SkyGuide.**

COMMUNITY

Reader Photo Gallery

Browse thousands of beautiful astroimages like this one from the 2015 Texas Star Party. Submit your own images at **www.Astronomy.com/readergallery.**


JON TALBOT

News

Get the latest updates on planetary missions, discoveries from space telescopes, results of cutting-edge research, and previews of the biggest celestial events of the year at **www.Astronomy.com/news.**

FOLLOW *ASTRONOMY*
www.twitter.com/AstronomyMag
www.facebook.com/AstronomyMagazine
plus.google.com/+astronomymagazine

INDEX *of* ADVERTISERS

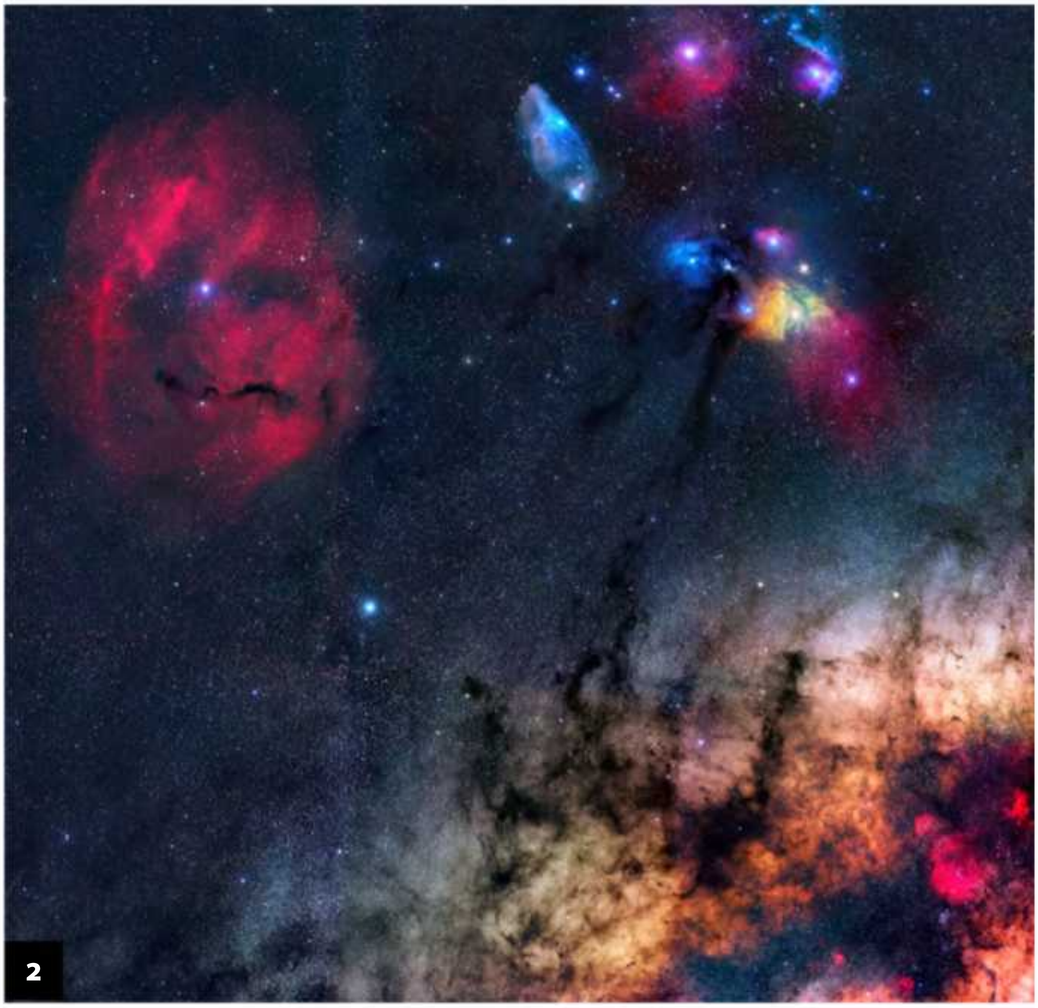
ADM Accessories 71
Adorama 15
AP Theory 70
Armstrong Metalcrafts 71
Ash Manufacturing 70
Astro Haven 15
Astro-Physics 17
AstroClosets 71
Astrodon 71
Astronomy Calendars 70
Astronomy magazine 69
Astronomy magazine - Digital Edition . . 65
Astronomy Travel Tours 21, 66
Bob Berman Tours 17, 67
Bob's Knobs 71
Celestron 2, 76
Glatter, Howard 71
iOptron 15
ISTAR Optical 71
Jewelry Designs for Men 70
Jim's Mobile, Inc. 67
MallinCam 67
Oberwerk 70
Obsession Telescopes 70
Oceanside Photo & Telescope 7
Omegon 3
Optic Wave Laboratories 71
Orion Telescopes & Binoculars 5
Rainbow Symphony 15
ScopeStuff 67
SkyWatcher - USA 75
Stellarvue 71
Technical Innovations 71
Tele Vue Optics, Inc. 11
The Teaching Company 8
Woodland Hills Cameras & Telescope . . . 17

The Advertiser Index is provided as a service to *Astronomy* magazine readers. The magazine is not responsible for omissions or for typographical errors in names or page numbers.


1

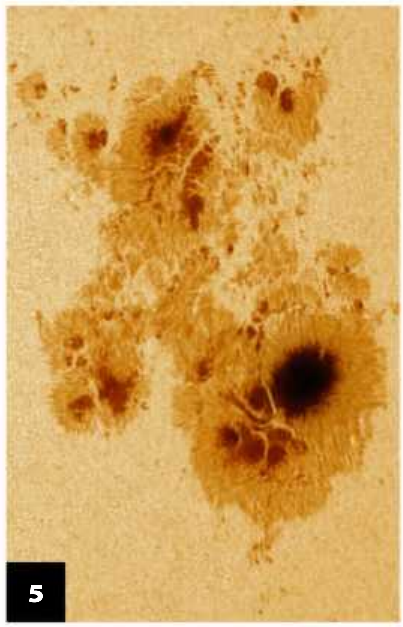
1. THE DARK WOLF
Barnard 228 is a dark nebula in the constellation Lupus the Wolf that's part of the Lupus Molecular Cloud. Such objects eventually will collapse to form star clusters. A portion of the Milky Way runs through this region giving it a high density of stars. (Canon 6D, Nikon 600mm f/4 ED IF lens set at f/6, ISO 1600, three-panel mosaic, each of which is one hundred and eighty-four 5-minute exposures, stacked)
• Scott Rosen

2. MILKY MOSAIC
This mosaic of the Milky Way in the constellation Scorpius the Scorpion shows a wide diversity of objects. Reddish emission nebulae vie with blue reflection nebulae, both of which hide behind dark nebulae. (FLI PL-16803 CCD camera, Canon 200mm f/2.0 lens set at f/5.6, six-field mosaic, each a 100-minute exposure)
• Gerald Rhemann


2

3

4



5

6

3. COSMIC BUBBLE
The Bubble Nebula (NGC 7635) is a cloud of ionized gas glowing because of a massive energetic star near the center of the bubble. That star is 50 times as massive and several hundred thousand times as luminous as our Sun. It lies 11,000 light-years away in the constellation Cassiopeia the Queen. (10-inch Deep Sky Instruments RC10C Ritchey-Chrétien telescope at f/7.3, FLI Microline ML11002 CCD camera, Hα/OIII/SII image with exposures of 10, 12, and 15 hours, respectively) ***• Jim Collins***

4. STREAMING LIVE
This image of spiral galaxy NGC 4414 shows the first color high-resolution depiction of the star stream halo surrounding the galaxy. This feature may be evidence for dwarf galaxies falling into NGC 4414. As they fell, they left trails of stars that loop around the much larger object. (32-inch Schulman Telescope, SBIG STX-16803 CCD camera, LRGB image with exposures of 12, 5, 5, and 5 hours, respectively) ***• Adam Block/Mount Lemmon SkyCenter/ University of Arizona/David Martinez-Delgado (U of A)***

5. MONSTER
This enormous and complex sunspot group makes up active region 2192. On the date of this image its diameter equaled that of Jupiter. Sunspots appear dark because they are cooler than the surrounding surface. (5.2-inch Opticon Schmidt-Cassegrain telescope, 1.8 Barlow lens, Imaging Source DMK 31AU03 webcam, taken October 23, 2014, at 10h01m UT) ***• Leo Aerts***

6. RARE AIR PAIR
Venus (brightest object) and Jupiter dance in the evening twilight over Lake Namtso in Tibet. In the Tibetan language, "Namtso" means "Heavenly Lake." It lies at an altitude of 15,485 feet (4,720 meters), and its water is a storybook crystal-clear blue. (Canon 6D, Sigma 35mm F1.4 DG HSM Art lens at f/4, ISO 1600, 10-second exposure, taken July 15, 2015) ***• Jeff Dai***

Send your images to:
Astronomy Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to readergallery@astronomy.com.

Swan song

Roughly 8,000 years ago, not long after the glaciers receded at the end of the last Ice Age, a spectacular explosion rocked the constellation Cygnus the Swan. A star with about 20 times the Sun's mass exhausted its store of nuclear fuel and ended its life as a supernova. The shock wave from the blast has now reached the walls of a cavity carved out by stellar winds from the pre-supernova star, creating the delicate tendrils of the Veil Nebula. The Veil spans some 110 light-years and covers 3° of sky. This new Hubble Space Telescope image shows a tiny 2-light-year section of the Veil's western lobe, known as the Witch's Broom (NGC 6960). NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

Astronomy's 2016 Guide to the Night Sky

LUNAR PHASES

New	First Quarter	Full	Last Quarter
			Jan. 2
Jan. 9	Jan. 16	Jan. 23	Jan. 31
Feb. 8	Feb. 15	Feb. 22	March 1
March 8	March 15	March 23	March 31
April 7	April 13	April 22	April 29
May 6	May 13	May 21	May 29
June 4	June 12	June 20	June 27
July 4	July 11	July 19	July 26
Aug. 2	Aug. 10	Aug. 18	Aug. 24
Sept. 1	Sept. 9	Sept. 16	Sept. 23
Sept. 30	Oct. 9	Oct. 16	Oct. 22
Oct. 30	Nov. 7	Nov. 14	Nov. 21
Nov. 29	Dec. 7	Dec. 13	Dec. 20
Dec. 29			

All dates are for the Eastern time zone. A Full Moon rises at sunset and remains visible all night; a New Moon crosses the sky with the Sun and can't be seen.

THE MOON is Earth's nearest neighbor and the only celestial object humans have visited. Because of its changing position relative to the Sun and Earth, the Moon appears to go through phases, from a slender crescent to Full Moon and back. The best times to observe our satellite through a telescope come a few days on either side of its two quarter phases. For the best detail, look along the terminator — the line separating the sunlit and dark parts. NASA/GSFC/Arizona State University

MARS stays visible throughout 2016, though it appears most conspicuous from March through September. The Red Planet rises around midnight in late March but comes up earlier with each passing day. It peaks at opposition in May, when it shines at magnitude –2.1, swells to an apparent diameter of 19", and remains on view all night. Mars hasn't appeared this bright and big since 2005. A telescopic view reveals subtle features that show up as contrasting shades of orange and brown. ESA/ROSETTA/MPS/OSIRIS TEAM

JUPITER always shows a dynamic face. Its atmosphere displays an alternating series of bright zones and darker belts pocked by the Great Red Spot. Even through a small telescope, the planet's four big moons appear conspicuous. You often will see them change positions dramatically during the course of a single night. Jupiter reaches its peak in early March, when it shines brightest (magnitude –2.5) and looms largest (44" across), though it's a fine sight into August and again from October until year's end. NASA/JPL/USGS

SATURN and its rings provide a spectacular attraction for telescope owners during most of 2016. The ringed planet is on display from January through early November, but it appears best around the time of opposition in early June. Saturn then shines at magnitude 0.0, and its disk measures 18" across, while the rings span 42" and tilt 26° to our line of sight. Even a small telescope reveals the dark, broad Cassini Division that separates the outer A ring from the brighter B ring. NASA/ESA/E. Karkoschka (University of Arizona)

WINTER

The sky

Winter boasts the brightest stars of any season. Orion the Hunter dominates the evening sky this time of year. Its seven brightest stars form a distinctive hourglass pattern. The bright blue star marking Orion's left foot is Rigel, and the ruddy gem at his right shoulder is Betelgeuse. The three stars of the Hunter's belt point down to Sirius, the brightest star in the night sky, and up to Aldebaran, the eye of Taurus the Bull. To Orion's upper left lies the constellation Gemini.

Deep-sky highlights

The Pleiades (M45) is the brightest star cluster in the sky. It looks like a small dipper, but it is not the Little Dipper.

The Orion Nebula (M42), a region of active star formation, is a showpiece through telescopes of all sizes.

The Rosette Nebula (NGC 2237–9/46), located 10° east of Betelgeuse, presents an impressive cluster of stars and a nebula.

M35 in Gemini the Twins is a beautiful open cluster best viewed with a telescope.

Castor (Alpha [α] Geminorum) is easy to split into two components with a small telescope, but the system actually consists of six stars.

SPRING

The sky

The Big Dipper, the most conspicuous part of the constellation Ursa Major the Great Bear, now rides high in the sky. Poke a hole in the bottom of the Dipper's bowl, and the water would fall on the back of Leo the Lion. The two stars at the end of the bowl, called the Pointer Stars, lead you directly to Polaris, the North Star. From the bowl's top, simply go five times the distance between the Pointers. Spring is the best time of year to observe a multitude of galaxies. Many of these far-flung island universes, containing hundreds of billions of stars, congregate in northern Virgo and Coma Berenices.

Deep-sky highlights

The Beehive Cluster (M44) was used to forecast weather in antiquity. It is a naked-eye object under a clear, dark sky, but it disappears under less optimal conditions.

M5, a conspicuous globular cluster, lies between the figures of Virgo the Maiden and Serpens Caput the Serpent's Head.

The Whirlpool Galaxy (M51) is a vast spiral about 30 million light-years away.

M81 and **M82** in Ursa Major form a pair of galaxies that you can spot through a telescope at low power.

Jan. 4 Quadrantid meteor shower peaks

Jan. 8 Venus passes 0.09° north of Saturn

Feb. 6 Mercury is at greatest western elongation

March 8 Jupiter is at opposition

March 8 Total solar eclipse

April 18 Mercury is at greatest eastern elongation

May 5 Eta Aquariid meteor shower peaks

May 9 Mercury transits the Sun

May 22 Mars is at opposition

June 3 Saturn is at opposition

July 7 Pluto is at opposition

Star maps by *Astronomy*: Roen Kelly

Aug. 12
Perseid meteor shower peaks

Aug. 25
Mars passes 4° south of Saturn

Aug. 27
Venus passes 0.07° north of Jupiter

Sept. 1
Annular solar eclipse

Sept. 2
Neptune is at opposition

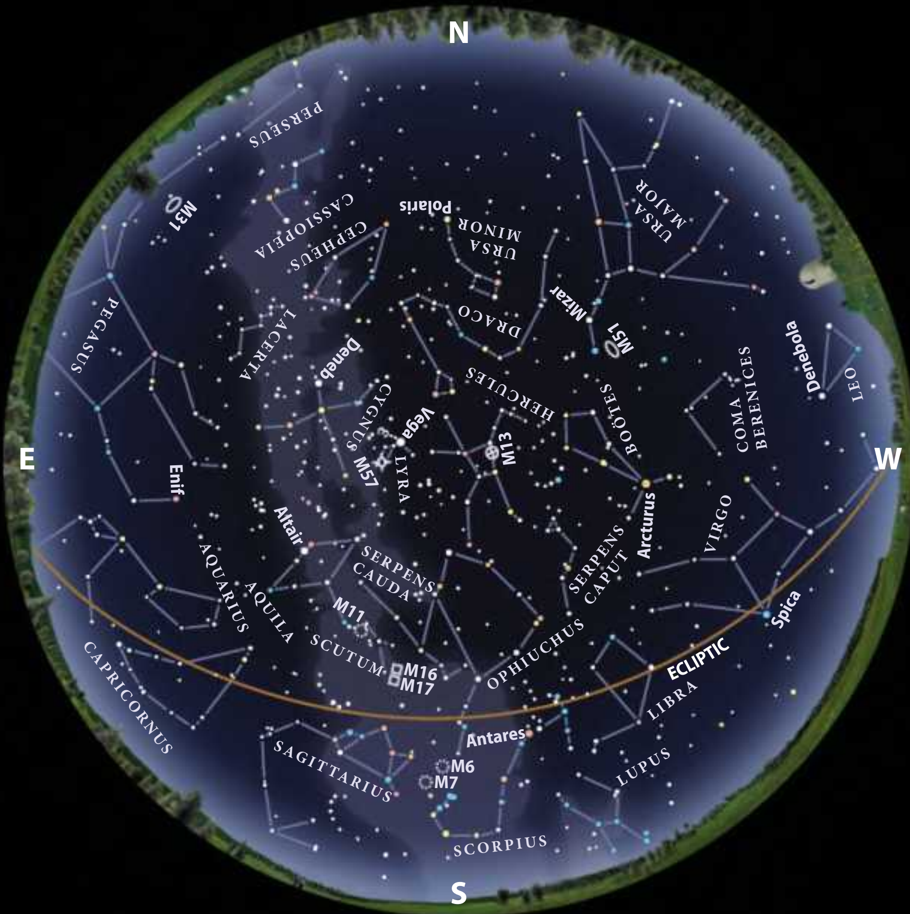
Sept. 28
Mercury is at greatest western elongation

Oct. 15
Uranus is at opposition

Oct. 21
Asteroid Ceres is at opposition

Oct. 30
Venus passes 3° south of Saturn

Dec. 10
Mercury is at greatest eastern elongation



SUMMER

The sky

High in the sky, the three bright stars known as the Summer Triangle are easy to spot. These luminaries — Vega in Lyra, Deneb in Cygnus, and Altair in Aquila — lie near the starry path of the Milky Way. Following the Milky Way south from Aquila, you'll find the center of our galaxy in the constellation Sagittarius the Archer. Here lie countless star clusters and glowing gas clouds. Just west of Sagittarius lies Scorpius the Scorpion, which contains the red supergiant star Antares as well as M6 and M7, two brilliant clusters that look marvelous at low power.

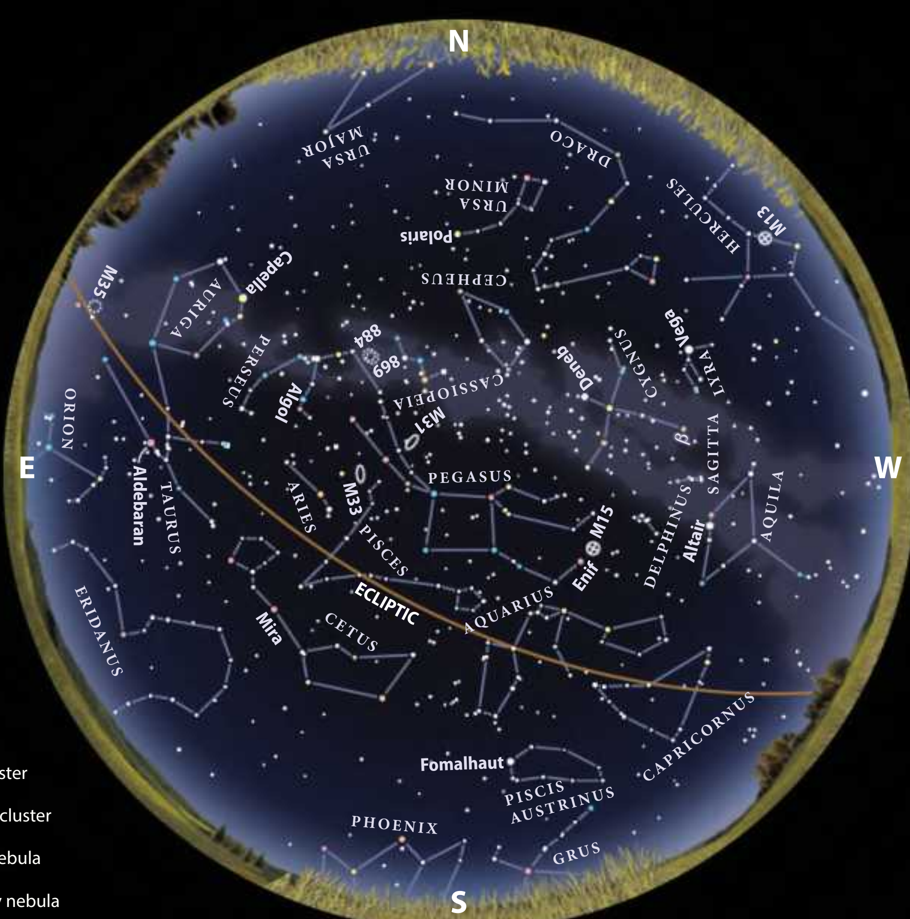
Deep-sky highlights

The Hercules Cluster (M13) contains nearly a million stars and is the finest globular cluster in the northern sky.

The Ring Nebula (M57) looks like a puff of smoke through a medium-sized telescope.

The Omega Nebula (M17) looks like the Greek letter of its name (Ω) through a telescope at low power. This object also is called the Swan Nebula.

The Wild Duck Cluster (M11) is a glorious open star cluster. On a moonless night, a small scope will show you some 50 stars.



AUTUMN

The sky

The Big Dipper swings low this season, and from parts of the southern United States, it even sets. With the coming of cooler nights, Pegasus the Winged Horse rides high in the sky as the rich summer Milky Way descends in the west. Fomalhaut, a solitary bright star, lies low in the south. The magnificent Andromeda Galaxy reaches its peak nearly overhead on autumn evenings, as does the famous Double Cluster. Both of these objects appear as fuzzy patches to the naked eye under a dark sky.

Deep-sky highlights

The Andromeda Galaxy (M31) is the brightest naked-eye object outside our galaxy visible in the northern sky.

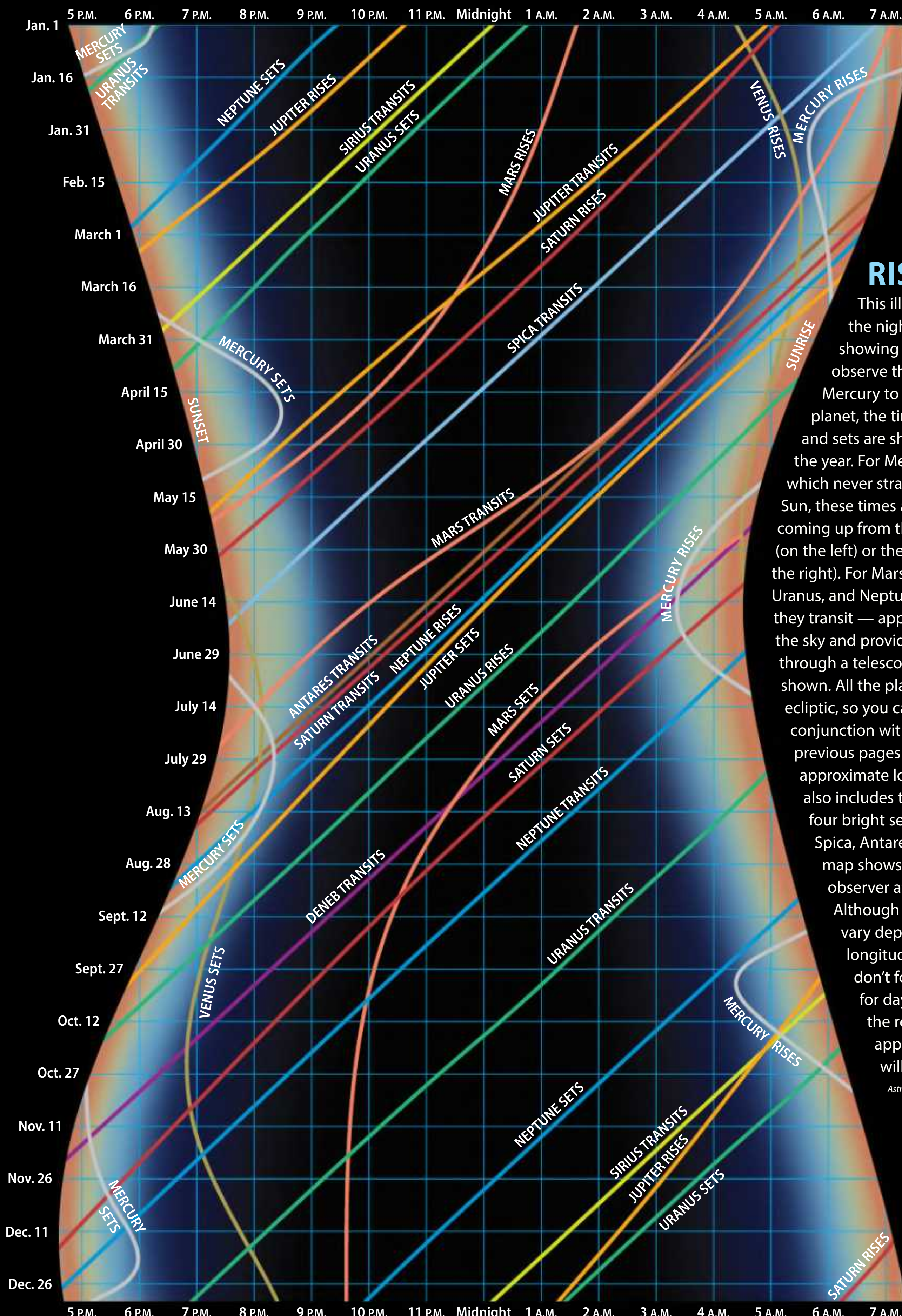
The Double Cluster (NGC 869 and NGC 884) in Perseus consists of twin open star clusters. It's a great sight through binoculars.

M15 in Pegasus is a globular cluster containing hundreds of thousands of stars, many of which can be glimpsed through a medium-sized telescope.

Albireo (Beta [β] Cygni), the most beautiful double star in the sky, is made up of suns colored sapphire and gold.

Open cluster
Globular cluster
Diffuse nebula
Planetary nebula
Galaxy

Astronomy magazine



RISE & SET

This illustration presents the night sky for 2016, showing the best times to observe the planets from Mercury to Neptune. For each planet, the times when it rises and sets are shown throughout the year. For Mercury and Venus, which never stray too far from the Sun, these times appear as loops coming up from the sunset horizon (on the left) or the sunrise horizon (on the right). For Mars, Jupiter, Saturn, Uranus, and Neptune, the times when they transit — appear highest in the sky and provide the best view through a telescope — also are shown. All the planets lie near the ecliptic, so you can use this chart in conjunction with the maps on the previous pages to find a planet's approximate location. The chart also includes the transit times of four bright seasonal stars: Sirius, Spica, Antares, and Deneb. This map shows local times for an observer at 40° north latitude. Although exact times will vary depending on your longitude and latitude (and don't forget to add an hour for daylight saving time), the relative times and approximate positions will stay the same.

Astronomy: Rick Johnson

MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

March 2016: Jupiter at its peak

As evening twilight fades in March, gaze in the opposite direction for a magnificent view of **Jupiter**. The solar system's largest planet lies low in the east as darkness falls but climbs high in the north by midnight local time. This is the best month of the year for watching Jupiter because it reaches opposition and peak visibility March 8. It then shines brightest, at magnitude –2.5, and dominates the night sky from its perch in southern Leo.

Opposition also marks Jupiter's closest approach to Earth, so the gas giant appears largest (44" across) through a telescope and shows a lot of detail even with small instruments. The best time for viewing comes when it rides high in the north and its light traverses less of Earth's turbulent atmosphere. Look for an alternating series of bright zones and darker belts that run parallel to one another and to the planet's equator. In moments of good seeing, other atmospheric features will pop into view. Jupiter's four Galilean moons also shine brightly enough to show up through any scope.

Two more bright planets appear later on March evenings. The first to rise is **Mars**, which comes up shortly after 10 P.M. local time early in the month and about 90 minutes earlier by month's end. It moves eastward relative to the background stars, passing from Libra the Scales into Scorpius the Scorpion at midmonth. Keen-eyed observers might notice the planet's progression slowing. It will reverse direction in April in advance of its May opposition.

With Mars heading toward its peak, the Red Planet's apparent diameter grows significantly, from 8.7" to 11.7", in March. Particularly by month's end, moderate apertures will offer pleasing views of its dusky face. Look in particular for the bright north polar cap and more-subtle dark markings across the rest of its surface.

Beautiful **Saturn** follows Mars into view in the eastern sky. The ringed planet lies in Ophiuchus the Serpent-bearer and appears almost directly below ruddy Antares, the brightest star in neighboring Scorpius, as they climb above the horizon. At magnitude 0.4, the planet appears noticeably brighter than the star.

By the small hours of the morning, Saturn stands high in the north and looks stunning through any telescope. At midmonth, the rings span 38" and circle the planet's 17"-diameter disk. With the ring system tilted 26° to our line of sight, observers should be able to spot the dark Cassini Division that separates the two brightest ring components.

For those who stay up all night or rise shortly before the Sun, **Venus** continues to grace the eastern sky. In mid-March, it comes up nearly two hours before the Sun and climbs nearly 10° high an hour before sunrise. Gleaming at magnitude –3.8, the planet stands out in the morning twilight. Unfortunately, Venus appears only 11" across and almost fully illuminated.

Mercury stands below Venus in the early morning sky during March's first ten days, but then gets swallowed by the twilight glow. Like Venus, it offers little to telescope owners, showing a nearly fully lit disk spanning just 5".

A **total solar eclipse** takes place March 9 along a narrow track that runs from the eastern Indian Ocean through Indonesia and the North Pacific Ocean. The only Southern Hemisphere locations in the path are parts of Sumatra, Borneo, and Sulawesi. People in western and northern Australia can witness a partial eclipse.

A **penumbral lunar eclipse** occurs March 23 for those on the Pacific Rim, with the best viewing spots south of the equator in Australia and New Zealand. Because the Moon only passes through Earth's lighter penumbral shadow, the dimming can be tricky to observe. Watch for a slight shading on the Moon's southern half that peaks at 11h47m UT.

The starry sky

Many countries show stars on their flags. But when it comes to constellations, the clear winner is Crux the Southern Cross. Australia, New Zealand, Papua New Guinea, and Samoa all depict Crux prominently.

Another national flag that features this constellation is that of Brazil, though, at first glance, the presence of the Southern Cross is not so obvious. The reason is that the Brazilian flag shows 27 stars — all of them real. The suns belong to nine constellations: Canis Major, Canis Minor, Carina, Crux, Hydra, Octans, Scorpius, Triangulum Australe, and Virgo.

Crux is the only one of these constellations that is easy to recognize, though even it appears rather odd. This is because the stars are shown as they would appear from the outside of an imaginary celestial globe. Therefore, they are reversed, as if seen in a mirror.

Twenty-six of the 27 stars on the flag represent one of the states of Brazil, and because some states were added in relatively modern times, so have some of the stars. The four most recently added states and their stars — all from Canis Major — were Rondônia (Gamma [γ]), Tocantins (Epsilon [ε]), Amapá (Beta [β]), and Roraima (Delta [δ]).

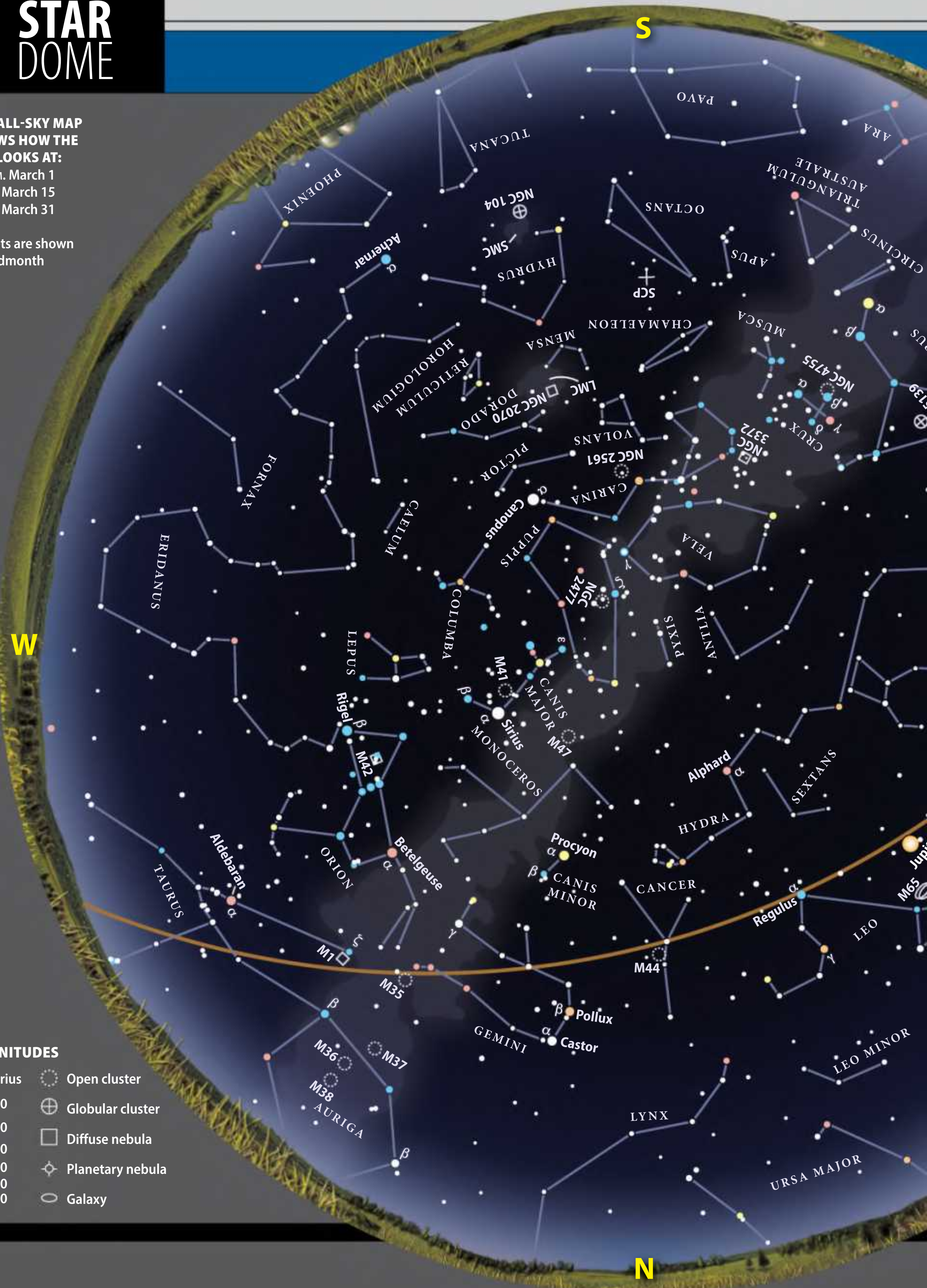
The flag's remaining star, Sigma (σ) Octantis, resides near the bottom of the flag. The flag's designers used Sigma, despite its being barely visible to the unaided eye, because it is the nearest naked-eye star to the South Celestial Pole and thus moves the least as Earth rotates. For that stability, Sigma represents the Federal District of Brazil, which includes Brasília, the country's capital.

A curious feature of the flag is that only one of the stars appears above the central banner, which reads *Ordem e Progresso* ("Order and Progress"). The odd one out is Spica, which seems to have been placed above to best represent its relative position in the sky.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
10 P.M. March 1
9 P.M. March 15
8 P.M. March 31

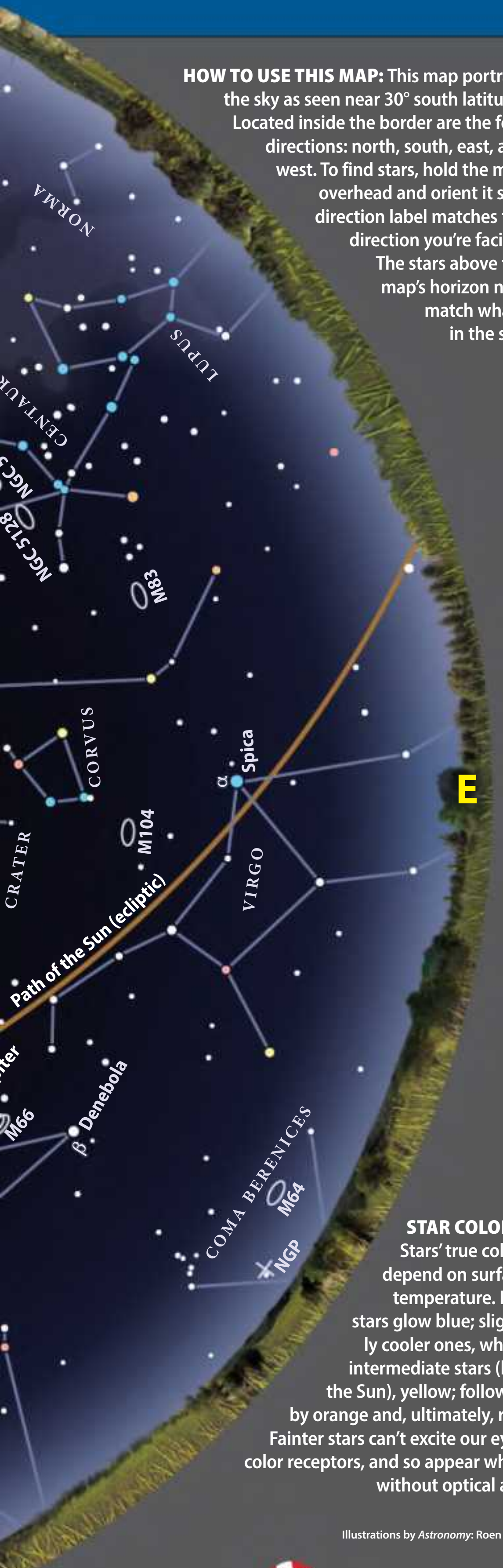
Planets are shown at midmonth



MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy



HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

MARCH 2016

Calendar of events

1 Last Quarter Moon occurs at 23h11m UT

2 The Moon passes 4° north of Saturn, 7h UT

3 Asteroid Ceres is in conjunction with the Sun, 22h UT

6 Asteroid Juno is stationary, 16h UT

7 The Moon passes 4° north of Venus, 11h UT

8 Jupiter is at opposition, 11h UT

9 New Moon occurs at 1h54m UT; total solar eclipse

10 The Moon is at perigee (359,510 kilometers from Earth), 7h04m UT

11 The Moon passes 1.9° south of Uranus, 1h UT

14 The Moon passes 0.3° north of Aldebaran, 14h UT

15 First Quarter Moon occurs at 17h03m UT

16 Asteroid Hygeia is at opposition, 0h UT

20 March equinox is at 4h30m UT

Venus passes 0.5° south of Neptune, 14h UT

22 The Moon passes 2° south of Jupiter, 4h UT

23 Full Moon occurs at 12h01m UT; penumbral lunar eclipse

Mercury is in superior conjunction, 20h UT

25 Saturn is stationary, 13h UT

The Moon is at apogee (406,125 kilometers from Earth), 14h17m UT

28 The Moon passes 4° north of Mars, 19h UT

29 The Moon passes 3° north of Saturn, 15h UT

31 Last Quarter Moon occurs at 15h17m UT